A PRACTICAL TREATISE

ON THE

PREPARATION, COMBINATION AND APPLICATION

OF

CALCAREOUS AND HYDRAULIC LIMES AND CEMENTS,

COMPILED AND ARRANGED FROM THE BEST AUTHORITIES, AND FROM THE PRACTICAL EXPERIENCE OF THE COMPILER DURING A LONG PROFESSIONAL CAREER,

TO WHICH IS ADDED MANY

USEFUL RECIPES FOR VARIOUS SCIENTIFIC, MERCANTILE AND DOMESTIC PURPOSES.

BY

JAMES G. AUSTIN,

ARCHITECT.

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PREFACE.

The following pages (which make but little pretensions to originality) are presented to the notice of the Building Profession, as a concise and useful work upon the important subject of Limes and Cements, and with a view to attract public attention to their essential properties, analysis, combination and application, as described in a rare, but highly esteemed and valued work (long since out of print) by Dr. Brindley Higgins, the theories and experiments therein enunciated and defined having been practically confirmed by the compiler, during a long professional career, and also as embodying the best modern experience and information upon the subject, derived from high authority (which is duly acknowledged) interspersed with practical remarks by the Author, to which is added much that is useful to the engineer, geologist, and American citizen, and now humbly and respectfully submitted to the patronage of an enlightened public.

March, 1862.

GENERAL REMARKS.

Cements are of two distinct classes, viz., *Calcareous*(or those which are used for works exposed to the air;) and *Hydraulic*,(or such as are used under water;)they are also further distinguished as *Hot* and *Cold*. The former are those which are applied by the aid of heat or fire, and which contain, rosin, resin, bees-wax, and such like substances; and the latter, those which are applied through the medium of alcohol, water, or oil, and are chiefly composed of calcareous and other earthy matters.

Calcareous Cement or mortar is a most important auxilliary in the construction of every description of brickwork, and masonry, and is universally known by the term "mortar."

Hydraulic Cements are those whose property is to indurate or to harden under water, and are consequently indispensable in the construction of bridges, docks, quays, and other marine works.

Plastic Cements are such as are more particularly applied to the stuccoing or incrustation of the exterior and interior surfaces of walls, &c., the use of which is more applicable to the plasterer's art.

The above three classes or divisions will be separately treated and explained, in consecutive order—but before entering into the description of the composition of either of them, it would be necessary first to consider and to define the nature, properties, and qualifications of the several ingredients of which ordinary mortar is composed, and to describe the principal varieties in use, pointing out the relative use and value of each, and then to describe the proportions of the several ingredients, and afterwards to explain the mode of combining and applying them to building purposes.

COMPONENTS OF MORTAR.

Lime.—Of this important ingredient there are numerous varieties possessing different qualities and merit. They are prepared from the following minerals, viz.: marble, limestone (of which there are several varieties), chalk, oyster and other shells, and also from other calcareous or carboniferous stones, which, when subjected to a red heat and calcined, will dissolve and effervesce with acid; and as a general rule it may be remarked that the harder the stone or other material is, the better will be the quality of the lime, and that which dissolves the quickest, heats the most in slaking, and falls into the finest powder, *is the best.*

Lime is usually found in connection with an acid, and by subjecting it to a red heat the acid is evolved, leaving the lime in a pure state, which is then termed *caustic or quick lime*, and is then fit for admixture with the other ingredients to form mortar or cement.

Of the method of preparing lime from the crude material, it will be irrelevant here to speak, but the operation will be found amongst the "addenda" at the end of this treatise.

Lime should be used fresh from the kiln, or otherwise it must be secured from the air, in close casks or other receptacles, till required for use, or it will by exposure readily absorb the carbonic acid gas from the atmosphere, to discharge which is the principal object of burning or calcining it; and lime, when once it is slaked, should be immediately used or it would become *effete* or dead, or for all cementitious purposes, perfectly useless.

Limestones lose about four-ninths of their weight in burning, though they shrink but little, but when properly burnt and slaked to a powder, they acquire nearly double their former bulk.

Chalk and lime stones if equally fresh and well burnt, differ but little in their cementitious properties, but as slaked lime absorbs carbonic

gas in proportion to its texture (solidity), so it yields its cementing properties the more freely by exposure; therefore, although stone and chalk limes be equally good at first, yet there will exist a great difference, subsequently; because the latter becomes more readily affected or injured by the atmosphere than the former, upon which fact, the preference for stone limes has been obtained.

Dr. Higgins in his work on "Calcareous Cements" &c., section 2, entitled "Experiments and Observations on Limestone and Lime," makes the following observations (the result of practical experiments) upon the properties of limestones, chalk and lime:—

Observation 1. *Limestone or chalk* heated only to redness, in a covered crucible, or a perforated one, through which the air circulates freely, loses only about one-fourth of its weight, however long this heat be continued. The sort of lime so formed, effervesces considerably in acid, slakes slowly and partially to a gray or brown powder, and heats but little in slaking; by *heat* is meant that degree of it which the bodies themselves (limestones, &c.) are made to conceive equally through their whole mass during the operation of burning.

Obs. 2. *Limestone or chalk* exposed to a heat barely sufficient to melt copper, whether in a perforated crucible or otherwise, loses about one-third of its weight in twelve hours, and very little more in any longer time. This lime effervesces but slightly in acids, heats much sooner, and more strongly than the former when wetted, and slakes more equally and to a whiter powder. In a variety of trials this lime equalled the best specimens prepared in common lime- kilns, and the amount of acidulous gas obtainable from each by a stronger heat, or in solution, were nearly equal; they slaked in like periods, with the same phenomena, color, and condition of powder.

Obs. 3. The lime burned in perforated crucibles, or in the naked fire, is whiter than that burned in common crucibles, covered, in which latter case the air has not free access to it, although the loss of weight be the same in both; but this latter kind of lime, in slak-

ing, affords as white a powder as any other which has lost equally of its weight. Whatever portion of phlogiston it retains to produce the dusky color, it is either detached in slaking, or does not sensibly affect the lime in any use to which it may be applied.

Obs. 4. When dry chalk or limestone is used in the process above described for making lime in close vessels, and for examining the matter which is expelled by fire, the quantity of water obtainable from it by heat is so inconsiderable as to deserve no notice in the calculation of that matter.

Obs. 5. Chalk or limestone heated gradually in close vessels loses very little acidulous gas until it begins to redden, after which the elastic fluid issues from it quicker as the heat increases, and so continues until the vessel attains a heat sufficient to melt steel.

Obs. 6. Forty-eight ounces of chalk yield twenty-one ounces of elastic fluid, the first issues of which are turbid, but soon become clear without loss of bulk, by the condensation of the aqueous fluid; the remaining portions being transparent and invisible, one thirty-sixth part of this elastic fluid, and sometimes even more, is phlogistic air, the residue, pure acidulous gas.

Obs. 7. The residuary lime of forty-eight ounces of chalk, heated to the total expulsion of the elastic fluids, weighs only twenty-seven ounces, when red-hot, but when cool it weighs more, by reason of the air which it absorbs as the heat escapes from it.

Obs. 8. When no more heat is employed than necessary to expel these elastic fluids, the residuary matter is sensibly diminished in volume, and is good lime, though not so white as lime prepared in the usual way; it slakes readily with water, and grows very hot and perfectly white. The slaked powder is exceedingly fine, except from those parts of the lime which lay in contact with the retort, which are always superficially vitrified, because clay and lime promote the vitrification of each other.

Obs. 9. The lumps of this lime, immersed in lime-water, or boiling

water, to expel the air which such spongy bodies imbibe in cooling, dissolve in marine acid without signs of effervescence.

Obs. 10. *Limestone* or chalk, gradually heated in a crucible, or on the bed of a reverbatory furnace, or in contact with the fuel in a wind furnace, does not become perfectly non-effervescent, and similar to the lime last described in slaking instantly, and in growing hissing hot when water is sprinkled on it, until it has, after a strong red heat of six or eight hours, sustained a white heat for an hour or more—by a *white heat*, that which will melt cast iron is meant.

Obs. 11. Limestones heated sufficiently to reduce them to lime which slakes instantly, and is perfectly non-effervescent, do not lose in general so much of their weight as chalkstone does under the like treatment. Some limestones lose little more than a third of their weight; those which lose the *most* slake the quickest, and to the finest powder; but those which lose the *least* slake the slowest, to a gritty powder, composed of true lime, and particles, chiefly gypseous.

Obs. 12. The quantity of gypsum, or other earthy matter, in well burned lime, is discoverable by weak marine acid, which dissolves and washes away the lime, leaving the gypsum to be measured when dry, the portion of which dissolved with the lime being too small to notice, and if any other earthy or saline matter existed in the limestone it vitrifies (with part of the calcareous matter) in the heat necessary for making non-effervescent lime, and is separable by the means last described, and in most instances, even by a fine sieve.

Obs. 13. When limestone or chalk is suddenly heated to the highest degree before mentioned, it vitrifies in those parts which touch the furnace or fire-vessel, or the fuel, and such portions become incapable of slaking freely, or making good lime, and limestone is the more apt to vitrify in such circumstances in proportion as it contains more gypseous or argillaceous particles; and oysters, or cockle shells, vitrify more easily than limestone or chalk, when they are suddenly heated, which is imputed to their saline matter, for when they have been long exposed to the weather they do not so easily vitrify.

Obs. 14. The agency of air is no further necessary in the preparation of lime than as it operates in the combustion of the fuel.

Obs. 15. Calcareous stones acquire the properties of lime in the highest degree when they are slowly heated in small fragments until they appear to glow with a white heat, when this is continued until they become non-effervescent, but is not augmented. The art of preparing good lime consists chiefly in these particulars, and as before remarked, the agency of air is no further necessary than to promote the combustion of the fuel.

Obs. 16. That lime is to be accounted the purest and most suited for experiment, whether it be the best for mortar or not, which slakes the quickest, heats the most, is whitest and finest when slaked, which, when wetted with lime-water, dissolves in marine acid or distilled vinegar without effervescence, and leaves behind the smallest quantity of residuary undissolved matter.

Obs. 17. The quick slaking, the color of the slaked powder, and the former acid are the most convenient and perhaps the best tests of the purity of the lime; the whiteness denotes the lime to be free from metallic impregnation, and the others show any imperfection in the operation of burning, and the heterogeneous matter inseparable from the calcareous earth by burning.

The mode of slaking lime, and the relative quantities to be employed in the composition of mortars will be hereafter explained.

OF SAND.

There are three distinct species in use for building purposes, viz.: river sand, pit sand, and sea sand; but of these the two former should only be admitted into the composition of mortar, and the latter is chiefly adapted for hydraulic cements, or such as will indurate under water, as applied to the construction of marine works—it should be pertinaciously excluded and rejected for any other purpose, and even in the most pressing emergency should not be employed as an ingredi-

ent of mortar, unless it has been previously well washed in fresh water to dissolve and dissipate all the saline and other objectionable matter, otherwise the mortar made with it will never properly harden, and will always imbibe the slightest humidity which may be present in the atmosphere or elsewhere, and conduct it through the work to its great damage and disfigurement.

There is, however, another ingredient used by many builders in lieu of either of the former, which, although when properly cleansed and prepared, assimulates very closely thereto, viz.: road-drifts, or the fractional particles of quartoze, granite, or other stones, broken off or detached by abrasion, or attrition, or by the traffic of the road: this, though, strictly speaking, not belonging to the category of building sands, is yet a very fair substitute, and recommends itself upon the score of economy; and, in cases where the former two species cannot be readily or cheaply obtained, is allowable.

But whatever variety of sand is employed in the composition of mortar or cements, it should be of a hard, gritty, and granular nature; angular, and having a polished surface; should be of nearly uniform size, and perfectly freed by ample washings (in clean water), and screenings from all organic matter, alluvium, salts and other foreign and injurious substances, which interrupt the perfect cohesion of its particles, and by their decomposition bring on a speedy destruction to the work. Sand when perfectly fit to be used in mortar, will bear the test of being rubbed between the hands without soiling them, and be free from any particular odor; these are good criterions of the purity of the sand—a most important matter to be attended to.

Dr. Higgins, in the 12th section of his treatise before referred to, entitled, "Experiments showing the best kinds and mixtures of sands, and the best method of using the lime-water in making mortar," writes thus upon the subject of sands, viz.: "Pursuing the analogy intimated in the 9th section, I thought that as large stones with curvilinear faces, imbedded in common mortar, do not form so strong a wall as they may when their interstices are filled with stones fitting

together with a due quantity of mortar, so mortar made with *sand* whose grains are nearly equal in size, and globular, cannot be so strong at any period of induration, as that which is mixed with as much fine sand as can easily be received into its interstices, in order that the lime may cement the grains by the greater number and extent of their contiguous surfaces." And he further adds: "It is to be observed that the sand which can pass through a sieve *in washing*, is considered finer than that which may be sifted through the same sieve when dry."

Sand is non-absorbent, that is, its volume is not increased by moisture, nor contracted by drought or heat, and its nature is imperishable, as is daily visible on the sea-shore, in the pit, or elsewhere, and its durability can be proved by a close inspection of specimens of mortar which have withstood the wear and tear of ages, and its character and purity are not less important than that of lime, in the composition of mortar. Of the proportions of sand to be used for various building purposes, due mention will be made when treating upon the preparation of mortar.

The following interesting experiments upon sand, are extracted from Dr. Higgins' work before mentioned. In section 3, he says: "I cleansed a large quantity of 'Thames' sand, by washing it in streaming water, and sorted it into three parcels; the coarsest which I call *rubble*, consisted of small pebbles, fragments of weathered shells, and grains of sand of divers sizes, which in washing had passed through a sieve, whose apertures were one-eighth of an inch square, but could not pass through a brass wired sieve whose meshes were one-sixteenth of an inch square, or rather more; the next parcel, which I called *fine* sand, consisted of grains of divers sizes, which in washing passed through a sieve whose meshes were one thirty-second of an inch square; the third parcel consisted of grains, the largest of which were washed through the coarsest sieve, and the smallest of those which were retained on the fine sieve; these I call *coarse* sand.

"Having dried these parcels on a sand plate, and provided a narrow-

mouthed glass bottle, capable of holding about two ounces, troy, of water, and a cylindrical glass vessel, which contained twelve of these measures, I found by repeated trials, that the large vessel, charged to the brim with my *rubble*, might be made to hold somewhat more than one additional measure of it, when the rubble was well-packed, by striking the bottom of the vessel repeatedly against the table perpendicularly.

"Charging the same vessel with *coarse* sand, I could, by the same treatment, make it hold two-thirds of the thirteenth measure; and twelve measures of *fine* sand were so far contracted by this motion of the vessel, that it could hold one measure and one-fourth more, or thirteen and one-fourth in all. After noting how far the intersticial spaces in each sized sand can be lessened by packing, I used water to show what proportion these bear to the solids in these different sands. I found that the thirteen measures of rubble which I stowed into the glass cylinder could take in *five* measures of water, without any *increase* of bulk; or rather with a striking *decrease* of bulk: the twelve measures and two-thirds of stowed coarse sand imbibed *four and one half* of water, and yet *decreased* sensibly in bulk: and the thirteen measures and one fourth of *fine* sand, packed, could drink in only *four* measures of water; but the diminution of bulk was more considerable in this than in either of the former, for the sand and water together measured less by one-seventeenth than the packed sand alone."

The importance of the foregoing experiments will be hereafter shown and explained. The Doctor then proceeds to say: "When sand was poured into the glass cylinder until it was filled, and the water added before the sand was packed, by a slight agitation of the vessel the sand contracted in a much greater degree than is above expressed. Upon the whole it seemed that *water*, by poising the grains, facilitates their sliding on each other, to fit well and fill the spaces.

"Until I had made these experiments I did not well understand, how the beating of new mortar makes it much wetter, and more plastic

withal, than it can be made with the same proportions of water and solids, by mere admixture. I now perceived that heating produces this effect by closing the interstices of the sand, and rendering a small quantity of lime paste as effectual towards filling them, and holding the grains together to form a plastic mass, as a greater quantity is, in sand whose grains cannot fit each other so well.

"Seeing that the intersticial spaces in sand are so greatly lessened by wetting it, I judged it expedient, for this reason alone, to expend all the water I should henceforth use in making mortar, in wetting the sand completely. I afterwards observed another advantage arising from this practice: for in filling the spaces with the fluid, the air is easily expelled, and the lime equally diffused in them by a little heating; but when the water is added to a mixture of lime powder and sand, the air is entangled in the lime paste, and cannot without a great deal of heating, be totally pressed out of the plastic mass. I likewise found that, as an excess of water is injurious to mortar, this is an excellent method of regulating the quantity of it; for the portion of lime water which fills the spaces in sand, and can be held by capillary attraction in a flat heap of it, is precisely the quantity which makes well-tempered mortar with one part of the best slaked lime, and seven of the best sand.

"As I experienced some difficulty in expelling the air bubbles out of the sand wetted in my deep cylindrical measure, even when I stirred up the mass with a slender instrument, I concluded that the spaces in sand are rather in a higher proportion to the solid substance of it than they appeared in these trials; so that we may say they are at least one-third and more of any measure of the fine sand, greater in coarse sand, and more so in rubble.

"Suspecting on another ground that these experiments did not show the whole of the spaces in sand, because water tends to insinuate itself between the contiguous surfaces of the grains, and consequently to remove them asunder, even whilst it arranges them, I attempted to ascertain the proportion of these spaces to the solids, by another method

founded on this supposition, that the measured portion of sand which weighs the most, has the smallest quantity of intersticial space.

"By experiment I found that a well-packed measure of the rubble weighed twenty ounces three pennyweights: the like measure of the coarse sand, packed, weighed twenty-one ounces eighteen pennyweights: and the same quantity, by measure of the fine sand, weighed twenty-three ounces two pennyweights and three grains.

"This trial corresponds sufficiently with the former in showing that the sum of the spaces in the rubble is much greater than that in the coarse sand, and that the spaces in the latter, are larger in the sum than those of the fine sand.

"In order to learn whether this proportion is maintained in *all kinds* of sand, I tried by water and by weight in the foregoing manner, a great number of the sands used in London, such as the coarsest glass-grinder's sand, Hampstead sand, Lynn sand, fine house sand, &c. The result of these experiments taught me that the spaces are always smaller as the sand is finer, provided the comparison be made between the sorted fine parts and the coarsest part of any kind of sand; but this does not hold true in the comparison of fine sand and coarse sand of different districts.

"On examining the several specimens of sand with a lens, I perceived that, in some, the grains, however different in figure, were bounded by flat faces meeting each other in angles, whilst in others the faces were generally rounded, and their figures such as the foregoing grains would be reduced to, by grinding off their angles. The first kind I call *sharp* sand, the other, *round* sand. Then taking into consideration the measurement already described, together with the sharpness or roundness of the sand, I found that the spaces are, in different kinds of sand, as the size and roundness of them compounded, but they don't appear to be smaller in any kind of sand that I have seen, than in one fine parcel of Thames sand, which I think is owing to its being sharper than any of the finer sands which I had compared it with. The measure which contained twenty-three ounces two penny-

weights twelve grains of the fine Thames sand, contained only twenty-two ounces ten pennyweights of the Lynn sand, which is a great deal finer, but rounder.

"Having thus found the kind of sand which, by reason of the size and figure of the grains, has the smallest intersticial space; I next endeavored to ascertain the mixture of coarse and fine sand, which lessens this space in the greatest degree, which therefore requires the less lime to cement the grains together, and for the reasons already mentioned, promises to make the hardest and most durable cement.

"I found that nine measures of the shingle, and an equal quantity of the fine sand, both well packed, measured, when mixed and stowed closely, sixteen measures and one eighth; that eighteen measures of the shingle, and nine of the fine sand, tried in the same way, measured twenty-four; and that on mixing the shingle and fine sand in various proportions, nine measures of shingle took into its interstices one measure and one-half of the fine sand without any increase of bulk.

"I next learnt that nine measures of the coarse sand, and nine of the fine, measured in like manner seventeen and a half; that eighteen such measures of coarse sand, well mixed with nine of the fine sand, measured twenty-six, and that on mixing these sands in various proportions, eighteen measures of the coarse sand took into its interstices one measure of the fine sand without any increase of bulk.

"Lastly, I found that eighteen such measures of the coarse sand, and nine of Lynn sand, which is much finer grained than the foregoing, measured twenty-four when well mixed and stowed; and that on mixing them in various other proportions, nine measures of coarse sand took into its interstices one and a half of the Lynn sand.

"By these and a variety of similar experiments made on different sands, I found that the quantity of fine sand taken into the interstices of the coarse sand was the greater without increase of bulk, as the grains of the coarse differed more from those of the fine in bulk, provided the diameters of the grains of coarse sand did not in general

exceed those of the fine in a proportion greater than five to one; that the greatest quantity of fine sand which could be taken into the interstices of coarse sand was one-sixth of the bulk of the coarse sand, and that in general the mixture of six measures of coarse sand with one of the finest sand, reduced the sum of the intersticial spaces to nearly one-half of the quantity of them in coarse only, or in fine Thames sand or rubble only.

"Instructed by these observations, I proceeded to the following experiments, in order to learn the advantages or defects attending each kind of sand, and how far my expectations from the art of lessening the spaces, were well founded.

"I made several parcels of mortar with my chalk-lime, lime-water, and rubble in different proportions; the quantity of lime being in one, a fourth of that of the rubble, in another only one seventh, and in the others intermediate: I also made other parcels of mortar with my chalk-lime, lime-water, and the coarse sand; and others with this lime, lime-water, and fine Thames sand, in the last mentioned proportions.

"I next made a great variety of specimens of mortar, some of which consisted of rubble and coarse sand mixed in different proportions, wetted with lime-water, and blended with one-fourth, or one-seventh, or intermediate quantities of lime; others were composed of similar mixtures of rubble and fine sand, with lime and lime-water; and others consisted of rubble, coarse sand, and fine sand, mixed in different proportions, wetted with lime-water, and beaten up with the different quantities of lime lately mentioned.

"I spread a part of each of these specimens of mortar, as soon as it was made, on a tile soaked in lime-water, half an inch thick in some places, and much thinner in others; I placed the remainder of it, formed into oblong pieces about an inch in diameter, on the part of the tile which was not covered with mortar; and I set all the tiles (numerically marked) in the situation formerly described, where they were equally exposed to the weather; during the succeeding twelve

months I examined each specimen, and noted my observations, the most useful of which I shall endeavor to relate in a few words.

"The specimens containing rubble and lime, mixed in any proportion greater than five to one, were not fat enough, when fresh, to be conveniently used in building or stuccoing; but none of them, not even excepting those which contained the greater quantities of lime, cracked in drying. Those which had the least quantity of lime in them were very rough on the surface, coarse in the grain, spongy, and easily broken; they showed a defect of lime, because those which contained more lime were not so bad in these respects. By all of which it appeared that whenever such rubble must be used for want of sand or finer gravel, the lime mixed with it must not be less than one-fifth of the quantity of rubble.

"Of the specimens consisting of coarse sand and lime, those which had the smaller quantities of lime, were too short for common use, and could not be made to assume a close and smooth surface whilst fresh, but in drying and hardening, they were in every respect preferable to the cements made with rubble and lime, in the same proportions; and of the same specimens those were the best which contained one part of lime in five ot sand, the others containing less lime, being faulty, like those made with rubble; and those in which lime was mixed in much greater quantity possessed the faults often observed to attend the excess of lime.

"The specimens which consisted of fine sand and lime were in general better than the foregoing, and that, particularly, which contained one of lime in six and a half of sand, was in all respects much better than those made with the same or any other quantities of rubble and lime, and coarse sand and lime. The specimen which was formed with seven parts of fine sand and one of lime, was not so compact and hard as that last mentioned. The comparison of these two showed that seven of sand are too much for one part of lime, when the sand is fine and unmixed with coarse grains. The specimen made with four parts of fine sand and one of lime, had the noted faults attending

the excess of lime; for it cracked in drying, and was sensibly injured in the winter, by those alternations of drying, wetting, freezing and thawing, formerly noticed.

"On divers comparisons of those portions of mortar made of fine sand and lime with the former, I was persuaded that a better cement can be composed with such sand as I call *fine*, than with a coarser sand, whose grains are all larger than any of those in my fine sand, provided the coarser sand be not much sharper than all I have yet seen. If my experiments had been made in slow succession, this last observation would have led me to imagine that the mortar will be found the better, as the sand is finer."

"Of the observations made on the parcels of mortar, consisting of mixed sands and lime, those which follow are the most pertinent to our present inquiry:—

"The specimens made with mixtures of rubble, coarse sand, and different quantities of lime, resembled those made with rubble and lime in similar proportions, when the rubble was predominant; and I could perceive no advantage derived from the mixture of the rubble and coarse sand, except that the cement was somewhat better, as the quantity of rubble was less, relatively to the quantity of sand and lime; but none of these specimens were in any respect so good as those made with fine sand only.

"Of the specimens made with rubble and fine sand, that was the best in which the fine sand was twice the quantity of the rubble. But I could not perceive that any of these specimens were preferable to those made with the like quantities of fine sand and lime, or that any considerable advantage is gained by the mixture of rubble and fine sand.

"Of the specimens made of coarse sand, fine sand, and lime, those were manifestly the best which consisted of four parts of coarse sand, three of fine, and one part or a little more of lime; for, while fresh, they were more plastic than the others, and were easily made to assume a smooth surface, they were not disposed to crack in this

method of drying, they were not at all injured by wet, or freezing, or thawing; they were pretty close in the grain, and they grew so hard in the course of nine or ten months as to resist the chisel, or any force tending to break the oblong pieces, much more powerfully than any of the specimens lately mentioned; I noted them as the best specimens of mortar that I had ever made, and one part of lime, in four of coarse and three of fine sand, to be a better proportion than any other of the sands and lime, for incrustations.

"Of the various samples of mortar made with mixtures of the rubble, coarse sand, and fine sand, those were the best in which the fine sand was equal or nearly so, in quantity, to the rubble and coarse sand, in which the rubble was not much more than one-seventh part of the quantity of both sands, and in which the weight of the lime was one-seventh of the weight of the sand and rubble, or a little more; but these specimens when fresh, were less plastic and less capable of assuming a smooth surface under the trowel, as the quantity of the rubble was greater; and I could not find that they were preferable in any particular to those respectively which were made with similar quantities of lime and the mixtures of coarse and fine sand lately recommended.

"Upon the strictest comparison, I concluded that one part of rubble in three of coarse and three of fine sand, makes as good mortar with lime as can be made with the sand and lime without rubble, for any purpose which does not require a finer cement, but there is no advantage gained by the use of rubble when the coarse and fine sand can be had equally cheap, unless a rough surface be required.

"In stuccoing walls, the rubble promised to be useful in pointing, and in the first coat, because a roughness of this coat makes the finer exterior coat adhere more firmly.

"In the review of all these specimens, it appeared that the quantity of lime which forms a mass somewhat plastic with sand and water, is the smallest quantity necessary for making the best mortar which such sand can afford, and that any further quantity of lime is useless in

the coarser sands, and injurious in the finer: that the necessary plasticity is induced by the smaller quantities of lime, as the interstices of the sand are smaller in the sum, and as the grains fit each other the better in consequence of the due mixture of coarse and fine sands; but that the lessening of the interstitial spaces, by the admixture of fine sand with the coarse, does not enable us to lessen the quantity of lime so far as might be expected, in consequence of our notions of the spaces measured by water. It seems that the grains of fine sand are held asunder by the lime paste, to a greater distance than they are by water, and that the reason why the finer sand requires more lime than the coarser and mixed sand, is, that the spaces which are more numerous in fine sand than in the coarse, are more augmented in the whole quantity of them, by the particles of lime, which intercede alike, the coarse and fine grains."

"Further allusion to this matter will be subsequently made. Of the several species of sand in general use for building purposes, that which is obtained from the bottom of fresh water rivers, or from the beds of rivulets and other water-courses, and known by the term "silt," is unquestionably the best; and next in quality is pit-sand, but this is in general too fine, and not so sharp and gritty as the former.

"Before closing these observations upon sand, it may be useful to remark that, in cases of emergency where proper sands cannot be readily obtained, ordinary gravel—if it be washed from all impurities, clay, &c., and well freed from all large round pebbles, and its particles sub-divided through proper sieves into two or three gradations of sizes, viz.: *coarse*, *medium*, and *fine*—may be used for constructive purposes, but its particles being round, or less *angular* than ordinary sand, do not so readily unite, and it consequently forms or produces mortar of an inferior quality."

The foregoing experiments are highly valuable and important, and evince great judgment, clear perception, and an indomitable perseverance and pertinacity to ascertain facts and establish truth, and

prove to a demonstration that a careful selection and admixture of coarse and fine sands in certain portions are preferable for mortar or cements than any sizes employed individually, because the smaller grains have the effect of filling up the interstices of the larger, thereby tending to consolidate the mass and to lessen the quantity of lime or other cementitious matter necessary to combine the whole. They also teach that it is far preferable to apply the great bulk of the water to the sand before incorporating it with lime, instead of mixing the two ingredients together before slaking; that by this method the air is more readily and freely expelled from the mass, and the mortar consequently becomes considerably improved. These results have been fully confirmed by my personal experience and observation during a series of many years professional practice in Europe and in distant parts of the globe, and I have generally found that the qnality of mortar (*cœteris paribus*) depends chiefly upon the purity of the sand, the form of its grains, and a due admixture of two or more differing sizes. The common practice of using unwashed sands, or road-drift, argillaceous loams, and even alluvium or common soil, charged as it is with vegetable and organic matter, cannot be too much reprehended, nor too speedily abolished. Builders are very apt to compound their mortar with the soil removed from the foundations of the sites of their buildings, alike regardless of its quality, or suitability for the purpose, or of the natural consequences of its employment.

WATER.

The last ingredient necessary in the formation of mortar is the aqueous element, the *nature* of which, being so well known to all, needs no description: but not so with respect to its components, for the value or quality of calcareous cements depends considerably upon the purity of the water. It must in all cases be fresh, and obtained from a river, pond, spring, well, brook, or any running water-course. but never from any stagnant pond or pool, which is always sur-

charged with vegetative and organic matter; nor should it be obtained from any spring or well which is oxydized (*i. e.*, containing mineral properties, examples of which are often to be met with); nor should the water contain any chalybeate or other chemical components; and sea-water is objectionable for the same reasons as explained in reference to sand, it being only allowable in the formation of hydraulic cements or marine mortar. Rain water is good if not kept long enough to vegetate or vivify.

Dr. Higgins has the following remarks upon the nature and use of water in the composition of cements, and recommends the use of *lime-water* as being far preferable. In section 7 of his work, "On the depreciation of mortar by the common method of using water, and of the use of lime-water," he says: "Finding by reason and experience the advantage of totally expelling the gas, and preventing the return of it to lime, or even to mortar before it is used, and knowing that common water, which is employed in great quantities, first in slaking limes and then in making mortar, contains a great deal of the noxious gas, it occurred to me that the vulgar process of making mortar is, in this fresh instance, *injudicious*, as it tends to injure materials otherwise good.

"Lime is slaked in such a manner that almost the whole of the water is evaporated, and contributes nothing to the mortar except so far as it deposits its gas in the lime, and injures it; and then the slaked dry lime and the sand require more water to make them into mortar. I have found the quantity of water used for both these purposes to be *twice* the weight of the lime at least. The quantities of *acidulous gas* known to be contained in the waters commonly used in making mortar, must greatly debase the lime which is thus exposed to double its weight of such water; and upon these grounds I was assured, *a priori*, that it would be a considerable improvement in mortar to use no water in it except what has been previously freed from acidulous gas.

"This is done in making *lime-water*, the use of which appeared advan-

tageous in another point of view. One seven-hundredth part of lime-water, being lime, (according to the experiments of Mr. Brandt, which I find to be true); and the lime being introduced in a state of solution, which favors the crystallization of it between the grains of sand, assists in cementing them together by the utmost attractive forces of its parts, if my notions of the polarity of these parts be true.

"I made divers experiments to try the practical validity of this reasoning, and found it to be true; for, on comparing specimens of mortar made with my best lime, slaked with river water, and sand and water, and spread on tiles soaked in water, with other specimens, made with the same proportions of lime, *slaked with lime-water*, and sand and lime-water, and spread on tiles previously soaked in lime-water, the latter, at every stage of them, were sensibly harder, and they adhered to the tiles better than the former. I must observe, however, that such distinctions (discoveries) cannot easily be made, except by those who have a great deal of experience in these trials and comparisons. On repeated examinations of these and my other specimens, I was highly encouraged in my pursuit, for those made with *lime-water* were better near the surface than any I had ever made, and I had good reason to be persuaded that the extraordinary induration would proceed in time, through the whole mass."

From the above experimental results, the superiority of "lime-water" over crude water, in the composition of mortar, is apparent, and the subsequent experience of many professional gentlemen fully confirms the said theorem, and as lime-water is easily prepared, even upon a large scale, by dissolving a quantity of lime in large casks or tanks, it behooves every one engaged in the execution of extensive and important works to adopt the plan.

Other ingredients are sometimes introduced into the compositions of mortar for particular purposes or objects, such as cinders, scoria, iron scales or filings, crude or burnt clay, pulverized potters' ware, or tiles, or other porous substances; they must, however, be pure and dry,

and rendered pretty fine by pulverization. Of these, however, we shall have occasion to speak hereafter, in the description of hydraulic and other cements for special purposes.

Of the Composition of various kinds of Mortar, their Application and Respective Values; with Occasional Notes of the Experiments and Opinions of Dr. Higgins and other first-class authorities.

Mortar as before mentioned, is generally composed of three ingredients, viz.: *Lime* (or cement), *Sand*, and *Water*, the respective properties of which may be defined as follows, viz.:—

1st. *Lime* is the cementing ingredient. 2d. *Sand* is the substance or matter (as relates to the mortar only) to be combined. 3d. *Water* is the element by which the combination of the lime and sand is to be accomplished.

Such being the relative uses and properties of the above mentioned ingredients, we must consider that lime being the cementitious medium, and the particles of sand the material to be united, through the agency or intervention of water, that it will require in the compostion of the mortar no more of the aqueous element than will effectually slake or dissolve the lime into a liquid paste, or make it free and convenient for use; and that of this cementitious paste, no greater quantity will be necessary than sufficient to conjoin or unite the several sides or angles of the sand together, or what is analogous, to fill the interstices between their bodies; and that the more effectually this can be done, the more compact and durable will be the mortar, the more excluded will be all damps and other atmospheric influences, and consequently the prevention of those destructive forces "expansion and contraction." This important desideratum can only be obtained by a judicious proportion and combination of the several component ingredients, and which Dr. Higgins and other qualified experimentors have already shown to be, with pure materials (*et cæteris paribus*), to

be one part of lime to five, six, or seven parts of sand—the relative proportion of the latter ingredient being dependent upon its description, and guage or size; because pit sand will require more lime (to make an equally good mortar) than sharp river sand, or clear road drift, and coarse sand will take less lime than fine sand, although obtained from the same source. This fact or knowledge resulted from the experiments of Dr. Higgins, before quoted, and proves the practical value of them. But where an undue or unnecessary quantity of lime is employed, the result will be, less compactness or solidity, imperfect induration, a disposition to imbibe and retain all moisture, and to sympathize with every atmospheric change; a constant disposition to expand and contract, and consequent liability to a more speedy decay.

With a view to determine the question or fact, Dr. Higgins made a series of impartial experiments, the result of which he gives as follows, in section 8 of his said treatise on calcareous cements, entitled, "Experiments made with a view to approximate the best proportions of lime, sand, and water for mortar":—

"In reading over my notes, and examining the specimens of mortar which I had hitherto made, I perceived that those were the best which being made with common fresh lime, or with well-burnt lime, *contained the least of it*; that is, one ounce of lime in six or more of sand; and finding that this quantity of lime to be much less than commonly used in making mortar; and suspecting that as a wall may be the weaker for its containing too much mortar (which widens the joints), so mortar may be weakened by the introduction of more lime than is necessary to cement the grains of sand together. I thought another cause of the defect of common mortar opened to my view, and that it was advisable to determine by experiment the best proportion of lime and sand in making mortar in which *lime water* is used.

"I made five parcels of mortar with my best stone lime, recently slaked with lime-water and coarse Thames sand, in the following proportions, *by weight*:—

	Slaked Lime.	Sand.	Water.
No. 1,	1	4	quantity sufficient.
" 2,	1	5	
" 3,	1	6	
" 4,	1	7	
" 5,	1	8	

"This latter specimen was not sufficiently plastic for common use, or as the workmen express themselves, *it was too short.* I further observed that the quantity of water required to make mortar to the proper temper is *more* as the quantity of lime is *greater*, relatively to the proportion of sand.

"I spread these specimens on tiles in the month of June, and exposed them to the air and sun, which then was very hot. As my former experiments taught me to expect that some of these in hasty drying would crack considerably, and as mortar in building is not liable to dry so quickly as these specimens, in order to render the inferences from these experiments the more general, I made five other parcels of mortar in the same manner, and exposed them in the same way, in every respect, except that the direct rays of the sun could not fall upon them, or heat the pavement on which they stood. In three days I found this necessary, for the first of those which stood exposed to the sun cracked considerably; the second, less; the third showed three or four very slender fissures, visible only on a very close inspection; and the fourth and fifth showed no cracks at this time, nor in a month afterwards, when the fissures of the other were considerably enlarged.

"Of the specimens kept in the shade, and examined on the third day like the former, the first was cracked in divers parts; the second showed two or three very slender cracks, and the rest were not cracked in the least, and never cracked afterwards, although I was forced to remove them to the place where the others stood.

"Thus it appeared in a very short time that an *excess* of lime disposes mortar to crack, and consequently injures it; that the highest proportion of lime to such sand, which may be used without incurring

this risk depends on the circumstances in which the mortar is to be exposed; that no more than *one part of lime to seven of coarse sand* ought to be used in mortar which is to dry quickly, and *less* lime may not be used, because it does not render the mass sufficiently plastic for building and incrustation; and that if a greater proportion of lime to such sand improves the mortar in any respect, it is to be used only when the mortar cannot dry so quickly as it did in the specimens exposed to the sun.

"In the course of nine months I clearly perceived that those specimens which stood in the shade for the first three days were harder and better in other respect than those which were suddenly exposed to the sun, the comparison being made between the specimens which contained a corresponding proportion of lime, and which cracked the least or not at all, and of all the specimens those were the best which contained one part of lime to seven of sand; for those which contained *less* lime, and were "too short" while fresh, were most easily cut and broken, and were pervious to water, and those which contained *more* lime, although they were closer in the grain, did not harden so soon, or to so great a degree, even when they escaped cracking by lying in the shade to dry slowly. I therefore concluded, that hasty drying injures mortar made in any proportions of such sand and the best lime, and that the best proportion is one of lime in seven of sand, whether the mortar is to be dried quickly or not.

"I must observe, however, that these conclusions were made rather with a view to my future experiments, in which an approximation to the best proportions of lime and sand, and the best treatment of the mortar would save a great deal of trouble, than to any general and invariable rules for making mortar.

"I reserved it to be mentioned here, that I set apart four ounces of each of the foregoing specimens of mortar, and spread them severally on plates of thin window glass, to the thickness of a quarter of an inch or thereabouts, and noted the weight of each plate with its specimens of mortar recently made.

"These being equally exposed to the sun, and weighed at different periods, were found to lose weight in equal times, nearly in proportion to the quantity of lime and water used in making them; and the smallest loss of weight when the specimens were perfectly dry and considerably hardened, was one-tenth of the weight of the same specimens recently made.

"In my former experiments, I had observed that mortar which sets without cracking, whether owing to the due proportion of sand, or to the slow exhalation of the water from mortar containing less sand, never cracks afterwards, whatever other faults it may have; and the specimens mentioned in this section, after a trial of eighteen months afforded the same observation.

"By the setting of mortar I mean that solidity which it acquires by mere drying, and which differs widely from the induration that takes place in time, by other means which we shall hereafter consider.

"Seeing then that the quantity of water is as the quantity of lime,—that the fissures happen only in the drying or setting—that the danger of cracking is greater, not merely as the quantity of water is greater relatively to the sand, nor merely as the water is more expeditiously exhaled, but in a rate compounded of these; I inferred that mortar which is to be used where it must dry quickly ought to be made as stiff as the purpose will admit, that is, *with the smallest practicable quantity of water*, and that mortar will not crack, although the lime be used in excessive quantity; provided it be made stiffer, or made to a thicker consistence than mortar usually is.

"This inference was afterwards confirmed, for specimens made thus with one part of lime and only six of sand, and others made with greater proportions of lime, but as stiff as they could be used, did not crack in any exposure, but they had faults which will be hereafter noticed."

Thus far the above described experiments fully demonstrate the advisability of employing a moderate proportion of lime and water to the quantity of sand, and that theory I have found correct during

many years of professional experience in Europe, Australia and elsewhere, and therefore confidently recommend it to the notice and trial of all persons engaged in the building art, in further allusion to which, the Doctor next proceeds (in Section 9,) to consider the "Theory of induration dependent on the proportion of lime and sand in mortar, and observations on the bad effects of the vulgar proportions of these." He says: "It is sufficiently known that the aggregation of calcareous bodies, which burn to lime, or are chiefly composed of the matter of lime, is much weaker than that of the quartoze (sand), in so much that the steel which easily cuts all calcareous stones or spars, is as easily cut by the siliceous, and all stones and powders which are chosen for cutting and grinding steel are found to have this effect by reason of their siliceous or quartoze particles. This being considered, together with divers observations heretofore related, I reason in the subsequent manner:—

"As stones are cemented together in walls by the mediation of mortar, so the grains of sand or gravel are made to cohere and form a solid mass of mortar, by the intervention of lime.

"By the bare inspection, as well as by the experienced induration, one part of lime paste appears sufficient to intercede the grains of seven of sand without interruption of continuity, and in drying, to fill the spaces between them, or to attract matter enough for this purpose from the air. In this case the grains cohere at the smallest distances of them, and by means of the thinnest laminæ of calcareous matter; and such mortar is the stronger as it consists of the greater quantity of hard quartoze bodies, cohering by means of the smallest practicable quantity of soft and brittle calcareous strata: just in the same manner as a wall built with porphyry and bad mortar is, (*cœteris paribus*) the stronger as the joints are made thinner; for all masses of such structures as mortar or cementitious walls resist fracture and ruin, with the powers of aggregation which are, not merely as the aggregate of the stones or brick, nor barely as the aggregate of the softer cements, but in a ratio compounded of these, and vary-

ing with circumstances which we need not attend to at present; and those masses therefore will resist the wind, in which the stronger aggregates bear the greatest proportion to the weaker, so far as it is consistent with the continuity of them.

"Secondly. The small stones which compose a heap of sand do not imbibe water, their volume is not increased by wetting them, nor lessened in drying; neither does a measure of wet sand contract sensibly in drying: this last I have repeatedly experienced; but small pieces of lime are considerably increased by wetting them; and as the soft paste of lime contracts greatly in drying, it must crack in every part where the drying paste is prevented, by its adhesion to bodies or by other causes, from contracting uniformly and concentrically. As the contraction of mortar in drying, and its consequent cracking depends on the lime paste, and not on the sand, they must take place in the greater degree, and they must be lessened or prevented by a due proportion of sand, which proportion experience shows (as before stated) to be seven parts of sand to one of lime. Thus we understand the cause of cracking, and how it happens that this defect is prevented by using less than the customary quantity of lime, and, although the lime should be used in excess, by using less than the customary quantity of water.

"Thirdly. The more perfect and expeditious setting and induration of mortar, containing only one part of lime in seven of sand, than of mortar made with greater proportions of lime, may be deduced from several concurrent causes. Having less water in its composition, it is sooner saturated with the matter which the air presents, and which seems necessary to the induration of mortar; and in this saturation, the swelling of the lime is not so great as to put forth and derange the grains of sand after they have once been placed, and in some degree cemented together.

"This latter inconvenience arising from the excess of lime, cannot easily happen in mortar compressed on all sides in massive buildings, but it manifestly occurs in the exterior parts of the joints in walls,

where the mortar visibly swells, and afterwards crumbles; it is likewise visible in the upper parts of walls of modern construction, where the swelling is not prevented by a superincumbent weight. In these cases the joints become hollow; houses lately built look old and ruinous, and the bricks themselves being bibulous in such position, soften and moulder, in consequence of the alternate wetting, drying, freezing, and thawing; these being effectual agents in the dissolution of all bodies which freely imbibe moisture.

"Without awaiting the event of those experiments which I have lately made on the great scale, and shall point out before I conclude this essay, we may on these grounds alone assure ourselves, that the strength and duration of calcareous incrustations composed of lime and sand, will be greater as we depart from the proportions of lime and sand *commonly observed*, approaching to that of one part of lime to seven of sand, because the stucco which hardens the soonest must be the least injured, whilst it is new, by the beating rains and various accidental impressions; because that which adheres the most firmly to the other materials of buildings, and which acquires the greatest degree of induration, must contribute most to the strength of the walls, and best withstand the shocks, attrition, and other trials to which the stucco is exposed; because that which contains the greatest proportion of sand, is less liable to be injured by any saline matter with which the air is sometimes impregnated, as its calcareous matter is best defended by the sand; but above all, because the stucco made with one part of lime and about seven of sand is not disposed to crack, for incrustations perish sooner by reason of the fissures than of any other defect, because the water imbibed into the smallest of them, as well as those which appear on a cursory view, swells in the congelation and dilates them, and frequent alternations of wetting and freezing, gradually widen them, until the stucco is bulged and torn from the walls."

In the early part of this treatize, allusion was made to the importance of the acidulous gas being completely discharged from the lime,

to effect which is the primary object in burning or calcining it, and that its value or utility depends upon the method in which this operaation is performed; in support of which theorem, a further reference will be made to the before-mentioned authority. In Section 4, he says: "On divers considerations it appeared to me, that the perfection of lime for mortar consists chiefly in the total expulsion of the acidulous gas; but to be better satisfied of this opinion, I made several parcels of mortar, the description of which will be abridged by observing in this place, concerning all of them, that the sand employed was coarse Thames sand, and that the lime was slaked as soon as it cooled after being burned, and with the smallest quantity of water necessary for this purpose, that it was sifted through a fine brass-wired sieve as soon as it was fully slaked, and that each parcel of mortar was beaten and briskly formed with the quantity of water which was barely sufficient to give it the usual consistence, which quantity is expressed in the usual term, *quan. suff.*

Sample.			
1	Sand 3 parts	Purest Stone Lime,	1 part.
2	6 "	" " "	1 "
3	3 "	" Chalk "	1 "
4	6 "	" " "	1 "
5	3 "	Stone Lime as Ob. 2,	1 "
6	6 "	" "	1 "
7	3 "	Chalk Lime as Ob. 2,	1 "
8	6 "	" "	1 "
9	3 "	Imperfect Limes as Ob. 1, of best Limestone,	1 "
10	6 "	" " "	1 "
11	3 "	Do. of inferior quality,	1 "
12	6 "	" " "	1 "

"MEM. The lime of Nos. 9, 10, 11 and 12 samples was slaked whilst it was hissing hot, in a covered vessel, because it would not slake sufficiently when it was suffered to cool before the water was sprinkled on it, or when its heat was soon dissipated by a free exposure to the air, and hasty evaporation of the water; and as this lime required

several hours to slake, I put it into a bottle as soon as it was cool, and kept it well stopped for twenty-four hours before using it. At the same time I made two specimens of mortar with common chalk lime and sand in the foregoing manner.

"Each specimen or sample was spread as soon as it was made, to the thickness of half an inch, on a plain tile previously soaked in water; the tiles were numbered and kept close by each other in an airy part of my laboratory until the mortar was dry, and then they were equally exposed, standing upright in a place where the sun and rain had free access to them.

"In the course of fourteen or fifteen months these specimens afforded me a great deal of information, which will be noticed in due time; even in the first six months they clearly indicated that lime is the better for mortar as it is more perfectly freed from acidulous gas. For when the comparison was made between specimens of mortar consisting of the same quantities of lime and sand, I found that the mortar made with well-burned non-effervescent lime, hardened sooner and to a much greater degree than mortar made with common lime, or my stone or chalk-lime burned in the manner expressed in the second observation of the second section; and the specimens made with the stone or chalk-lime which was least burned, were incomparably worse than any others, for they never acquired any considerable hardness, and they mouldered in the winter the *sooner*, as they contained more of the lime, and they also cracked more in the drying. I also observed that the specimens which contained the smaller quantities of well burnt lime cracked much less than the others, or not at all; that they adhered to the tiles more firmly, and were less injured by freezing; but as the specimens made with an excess of the well-burnt lime were no more cracked than those made with equal quantities of the other kinds of lime, and as I could distinguish the imperfections arising from the excess of lime, from those which proceeded from the bad quality of it, I was satisfied that the lime which is most completely burned is the best for mortar.

"Considering the heat which I found necessary to extricate the last portions of acidulous gas from chalk or limestone to be much greater than even adopted in making lime, so far as I had observed or learnt from others; I suspected that the lime, commonly in use, is seldom or never sufficiently burned.

"On repeated trials of several specimens of such lime, I found this suspicion to be well-founded, for they all effervesced and yielded acidulous gas, more or less, during the solution of them, and slaked slowly in comparison with well-burned lime; and in order to render the effervescence conspicuous, a *strong* acid ought to be used, because the quantity of water in a diluted acid retains a proportional share of the acidulous gas, and a certain quantity will retain the whole of it and prevent the effervescence, because the effervescence depends on the escape of the elastic fluid out of the solution. This is exemplified in the mixture of diluted vitriolic acid with the diluted solution of salt of tartar—for these solutions mix without effervescence, although a more concentrated solution of the alkali, mixed with vitriolic acid, effervesces violently.

"By several experiments I found that chalk-lime, when taken as fresh as it can be had from the wharf, consisting of pieces which, being well-burnt, contain, especially in their central parts, about one-twentieth of their weight of acidulous gas, of others which contain more, and of others which retain near half their original quantity; that these last are easily discoverable by their specific gravity and hardness, and that this is the part of our common lime which slakes the latest, and of the darkest color, or which never slakes at all. On a peck of this lime I sprinkled water, endeavoring to slake it equally by throwing the most water on those pieces which required it most. After the lime had stood a quarter of an hour to slake, I sifted it through a sieve whose apertures were one-sixteenth of an inch square, and then measuring the part which could not pass through the sieve, I found it to be one-fifth of a peck, upon which I sprinkled boiling water, and put into a close vessel, in a warm place, to accelerate the slaking of it.

"I made a parcel of mortar with one part of the sifted lime and three of sand, with a sufficient quantity of water; and another parcel with one part of the lime, six of sand, and the necessary quantity of water, and dried them upon tiles in the manner already related, in the month of April, the weather being dry. The foregoing coarse portion of the lime, after three hours, was slaked in several parts to a greyish powder, and I could perceive that more of it would slake in a longer time; I anticipated this by reducing the unslaked part to powder and mixing them together.

"With this powder and sand and water in the foregoing proportions, I made two specimens of mortar, and exposed them as I had done the former. In a few months it appeared that the specimens last mentioned scarcely deserved the name of mortar, whilst those made with the first slaked part of the lime were but little inferior to the best specimens made with the same proportions of chalk, lime, and sand.

"These experiments confirmed me in my opinion that lime is better for mortar, as it is free from acidulous gas; they showed one of the causes of the inferiority of common mortar, and how to manage ill-burnt lime when better cannot be had.

"Workmen usually slake lime mixed with sand or gravel in great heaps, and do not screen it until the most useful part is debased by that which slakes after five or six hours or more, and which is little better than so much powdered chalk. But if they would screen the lime in about half an hour after the water is thrown upon it, the mortar would be much better, although the quantity of lime in it should be much less; for I observed in all the foregoing specimens that those which contained the smallest quantity of lime were the best, and this quantity is much less than is usually employed in mortar.

"These remarks are applicable to mortar made with stone-lime, which is generally better than the chalk-lime, because it is obliged to be burned better, as it will not slake otherwise.

"In the brief relation of these experiments I have taken no notice of the flinty kernels which frequently occur in chalk-lime, or of other stony masses which differ from calcareous, and which are found in lime-stone, in order to avoid being led into errors.

"When first I noticed the quantity of chalk-lime which slakes late or not at all, I suspected that this difference might in some degree be owing to the admixture of argillaceous or other matter, but on trying these portions in acids, and after burning several specimens of them, I was convinced that the only impediment to their slaking consisted in their not being sufficiently burned in the kiln."

From the results of the foregoing experiments it is clearly demonstrated that much of the imperfection of mortar is owing to careless or imperfect manufacture of the lime, to say nothing of the loss in waste. All therefore interested or concerned in the building art should look well to this most important matter, as the durability of their works depends greatly upon the character of the mortar and other cementitious substances employed therein.

Before proceeding to describe the mode of slaking lime and preparing mortar, it may be well to record some further experiments made by Dr. Higgins, in reference to the chemical properties of lime, and of several effects produced upon lime and mortar by atmospheric or other agencies. His observations upon phlogisticated (inflammable) air, which abounds in all lime, are very pertinent to our subject, and we quote his words in Section 3 of his valuable treatise, entitled, "Remarks on the phlogisticated air which appeared in some of the foregoing experiments":—

"As phlogisticated air had not been noticed in any former experiment made on chalk or lime-stone, I resolved to examine the elastic fluid detached from them in the usual method. I extracted several gallons of elastic fluid from chalk, during the solution of it in marine acid, diluted largely with water, and after agitating this fluid with the necessary quantity of water, and sometimes with lime-water, until all the acidulous gas was imbibed by them, I found a residue consist-

ing of common air, which was about one-twenty-eighth of the bulk of the acidulous gas, in some trials, in others it was much less.

"As I have not had time to examine lime-stone in the same manner, or to prosecute this subject by other experiments, I must content myself with offering a conjecture concerning it.

"The air which is extracted during the solution of chalk seems to be that which chalk, like other porous bodies, imbibes by capillary attraction, and it retains its proper character, because all the phlogistic matter of chalk is held in the solution. It may happen likewise that some air escapes from the water while it imbibes the acidulous gas, which it attracts more forcibly; and this air from the water may contribute to the bulk of that which appears in the solution of calcareous bodies. But whilst chalk is deprived of its acidulous gas by the action of fire, the air which was held in its pores, and which attracts phlogiston, is expelled therewith, and consequently in the form of phlogistic air. This conjecture appears the more probable when we consider that the quantity of air imbibed by porous bodies is much greater than it appears in any experiments made with the air-pump, as shown by the great increase of weight, which red-hot charcoal acquires in cooling in vessels into which nothing ponderable but air was admitted. The same attractive powers which draw air into bodies, and then condense it, resist the expansion and escape of it in the void, and detain in such a situation of the bodies that quantity whose repulsive powers are counterposed by the attractive ones."

Experiments showing how quickly Lime imbibes Acidulous Gas, and is injured by Exposure to the Air.

"It was generally known that lime exposed to air loses those characters which chiefly distinguish it from whiting or powder of chalk, and that it resumes the acidulous gas which had been expelled from it in burning. But being desirous to know in what measure or time these

changes take place, and in what circumstances they are accelerated or retarded, I made the following experiments:—

"Exp. 1. I exposed two pounds (avoirdupoise) of well-burned non-effervescent chalk lime, in fragments of the size of a walnut, spread on a board, in a dry unfrequented room; I exposed the same quantity of this lime at the same time, and in the same manner, in a passage through which there was a constant current of air, and I put the same quantity of this lime, in fragments of the same size, in a box which might hold as much more of it, and placed the box loosely covered with its lid, close by the first portion of the lime.

"In twenty-four hours the superficial lumps of the first parcel cracked in some parts a little, those of the second cracked more, but those of the third were not visibly altered. In forty-eight hours the first parcel cracked so much as to fall into smaller fragments on being moved, and these were reducible to powder by pressing them between the fingers; the second parcel underwent the like, or rather greater change, for it was more cracked and friable; and the third now began to crack in the superficial parts. On weighing them, I found the first parcel weighed two pounds five ounces, the second, two pounds six ounces and one drachm, and the third, two pounds one ounce and ten drachms; I then returned them to their former stations.

"In six days the first parcel weighed two pounds ten ounces and seven drachms; the second, two pounds twelve ounces and one drachm; and the third, two pounds four ounces and eight drachms. In twenty-one days, the first weighed three pounds and one drachm; the second, three pounds two ounces and one drachm and a half; and the third, two pounds six ounces and eight drachms. During this increase of weight, the fragments split into smaller pieces. but did not fall into powder, except in a small part of them, or when they were handled.

"By similar experiments made on well-burned stone lime, I found that it imbibes matter from the air nearly in the same manner as chalk lime, but rather more slowly, which I think is owing to its

closer texture; and on exposing common chalk or stone lime in the same way, it was found to increase in weight much less, and more slowly.

Exp. 2. In order to discover the quantity of water which the lime imbibed from the air, and which contributed to this increase of weight, I put each parcel into a glass retort, and adjusting to it my apparatus whereby all that is condensed, is saved, whilst elastic fluids are at liberty to escape, I found that the quantity of water contained in each parcel of lime was nearly in some; and in others exactly one twenty-fourth of the gained weight, the remainder of which was acidulous gas, mixed with a little air; which latter was not reckoned, having been already weighed in the lime.

If a glass bottle be filled with fragments of well-burned chalk lime, or stone lime, and well closed with a ground glass stopple, waxed where it fits the neck of the bottle, the lime will remain unaltered in weight, or in any other particular for a year or two, as I have repeatedly experienced; even the phosphorescence of lime is thus preserved in its full lustre, for a year or more.

Thus it appeared that well-burned lime imbibes acidulous gas from the air, the sooner as it is the more exposed to it; that lime absorbs this matter from the open air, the more greedily as it is the more perfectly deprived of it, previously to the exposure; that lime cannot be ong preserved unaltered in any vessels which are not perfectly *air-tight*, but may be kept uninjured in air-tight vessels filled with it; that chalk lime by reason of its sponginess, or by some other condition of it, requires to be kept less exposed than stone lime, and well-burned lime less exposed than common lime, to render the depravation of them equal in equal times; that if acidulous gas imbibed in lime previous to its being used in mortar, be as injurious to mortar as the acidulous gas retained in an equal quantity of ill-burned lime is, lime becomes more unfit for mortar every hour that it is kept exposed to air, whether in a heap, or in casks pervious to air. Moreover these experiments show that lime undergoes these changes much quicker

than has been suspected, since well-burned chalk lime kept in a dry room, imbibes near a pound of acidulous gas in three weeks, in the summer season.

"Not trusting to *theory*, what I could prove by *experiment*, I did not rest satisfied with the observations and reasons which might persuade one, that lime which has imbibed some acidulous gas, is as unfit for the uses now under consideration as lime which retains an equal quantity of the like matter by reason of the deficiency of heat in burning it; I tried parcels of well-burned chalk and stone-lime, some of which were used fresh, others exposed two days, others six days, others twenty-one days; by making several specimens of mortar with them, and exposing these specimens in the manner already related; and in a few months I was satisfied that the specimens made with fresh lime were the hardest and best, and that the others were worse as the lime of them had been longer exposed, for those made with the lime which had been exposed three weeks, and had gained four or five ounces to each pound, were so easily cut or broken, so much effected by moisture and drying, and so liable to break off from the tiles, as to be utterly unfit for the ordinary uses of mortar.

"After this there remained no doubt that lime grows worse for mortar every day that it is kept in the usual manner, or in crazy casks; that the workmen are mistaken in thinking that it is sufficient to keep it dry; that lime may be greatly debased without slaking sensibly, and that the superficial parts of any parcel of lime, which fall into fragments or powder without being wetted, and merely by exposure to air, are quite unfit for mortar, since this does not happen until they have imbibed a great deal of acidulous gas.

"I now saw more clearly another cause of the imperfection of our common cements. The lime being exposed a considerable time before it is made into mortar, and drinking in acidulous gas all the while, the quicker as it is the better burned, is incapable of acting like good lime, when it is made into mortar, and often approaches to the con-

dition of whiting, which with sand and water makes a friable, perishable mass, however carefully it be dried.

"In London, particularly, they use lime which is burned at a distance of ten or twenty miles or more, with an insufficient quantity of fuel. This lime remains in the kiln to which the air has access, for many hours after it is burned; it is then exposed for some days in the transportation and on the lime wharves, and it undergoes further exposure and carriage before it is slaked into mortar. It is, therefore, no wonder that mortar is bad, if its imperfection depended solely upon the badness of the lime, since the lime is not only bad when it comes from the kiln, but becomes worse before it is used, and when slaked is as widely different from good lime as it is from powdered chalk."

Experiments and Observations made to determine whether Mortar becomes better for being kept long before it is used.

"I am generally disposed to think that there is some good reason for any practice which is common to all men of the same trade, although it may not be easily reconcilable to the notions of others; and seeing that the builders slake a great quantity of lime at once, more than they can use for some days, and that all those with whom I conversed, esteemed mortar to be the better for being long made before it is used, and that plasterers in particular follow this opinion in making their fine mortar or stucco for in-door work; I was desirous to discover the grounds of these measures so repugnant to the notions gathered from the foregoing experiments, and others. I therefore made about a peck of mortar with one part of the freshest and best chalk lime, slaked, six parts of sand, and water *quan. suff.*; for in a great number of experiments I observed that this proportion of lime was better than any larger which I had tried, or which the workmen observe in making mortar. The mortar was formed into an hemispherical heap on the paved floor of a damp cellar, where it remained untouched twenty-four days. At the expiration of which time, it was

found hardened at the surface, but moist, and rather friable or 'short than plastic in the interior parts of it. I beat the whole of it with a little water to its former consistence, and with this mortar and clean new bricks, built a wall eighteen inches square, and half a brick in thickness, in a workmanlike manner. On the same day I made mortar of the same kind and quantities of fresh chalk lime and sand, tempered in the same manner, and built a wall with it, like the former, near it, and equally exposed to the weather. I examined the mortar in the joints of these walls every fortnight, by picking it with a pointed knife, and could perceive a very considerable difference in the hardness of them, the mortar which was used fresh being invariably the hardest.

"At the expiration of twelve months, in pulling these walls to pieces, and by several trials of the force necessary to break the cement and separate the bricks, I found the mortar which had been used quite fresh to be harder and to resist fracture and the separation of it from the bricks in a much greater degree than the other experiment.

"Considering that mortar exposed in the foregoing manner must imbibe some acidulous gas, though not so much perhaps as the dry and spongy lumps of lime drink in during the same time; that the additional quantity of water necessary in beating it up the second time must have introduced more of the like matter, as all native waters contain some quantities of it; that the fresh exposure in the last mentioned agitation of the mortar must have contributed something to the same effect; and lastly, that the result of this experiment coincided with the notions already derived from others, I concluded that mortar grows worse every hour that it is kept before it is used in the building, and that we may reckon as another cause of badness of common mortar, that the workmen make too much at once, and falsely imagine that it is not the worse, but better, for being kept.

"Having in consequence of these observations had a great deal of conversation with workmen on this subject, I could perceive the origin of this error.

"Some portions of every kind of lime used do not slake freely, by reason of their not being sufficiently burned, or by the admixture of gypseous or argillaceous matter, and these, like marl, slake in time, though not so quickly as the purer lime.

"The plasterers, who use a finer kind of mortar made with lime and sand, observe that their plaster or stucco blisters when it contains such particles of unslaked lime: and as their purpose is to work their stucco to a smooth surface, and to secure from cracking, or any such roughness as would be occasioned by the slaking or moulding of bits of calcareous matter in the face of it; and as the hardness of the stucco is not their chief object, they very properly keep their mortar a considerable time before they use it, in order that the imperfect pieces of lime which passed through the screen may have time to slake thoroughly.

"It appears that there is another reason which the workmen do not notice for their process, which is, that lime imbibes so much acidulous gas from the air, as to become increased in bulk, and in weight beyond the half of its former quantity; and as stucco for inside work, for the sake of a fine grain and even surface, must have a greater quantity of lime in its composition than is necessary for cementing the grains of sand together, the incrustation would, by the access of acidulous gas after it is laid on, be apt to swell and chip, and lose the even surface if the lime were fresh when it is used in this excessive quantity; but this inconvenience is obviated by their processes, in which the lime, whether slaked into water or otherwise, imbibes a considerable quantity of the gas, and is, therefore, less apt to blister and swell, after the stucco is laid on. The builders, considering the plasterers' mortar or stucco as a finer and better kind of mortar, think it not amiss to imitate them in those particulars which are not attended with any expense, and especially in the practice of slaking a great deal of lime at once, and of keeping the mortar made some time; and they do not seem to know that such mode prevents the mortar from ever acquiring that degree of hardness in which the perfection of mortar truly consists.'

EXPERIMENTS AND OBSERVATIONS SHOWING THE AGENCY OF ACIDULOUS GAS IN THE INDURATION OF MORTAR, AND CIRCUMSTANCES WHICH IMPEDE OR PROMOTE IT. PRACTICAL INFERENCES.

"The observations made on divers specimens of mortar at different periods, led me early into the opinion that the setting of mortar depends chiefly on the exsiccation of it, but that the induration is principally owing to the accession of acidulous gas in certain circumstances, and not to the drying, as the workmen generally imagine. In order to place this opinion beyond a doubt, and to discover the circumstances which favor or impede this induration, I made the subsequent inquiries:—

"EXP. 1. I made mortar with seven parts of Thames sand, one part of the best slaked chalk-lime, and the necessary quantity of lime-water, and forming a part of it into oval pieces, I put these into a gallon bottle, stopped closely with a ground glass stopple, waxed; and I noted the gross weight of the bottle and mortar, and placed it exposed to the sun. Having examined it frequently during the first month, I could perceive no alteration in the weight, nor anything worth notice, except that some water exhaled out of the mortar, and condensed in bright drops on the sides and the upper parts of the bottle. At divers times during six months afterwards, I shook and weighed the bottle, and found the mortar quite soft, and the weight of the whole unaltered.

"EXP. 2. Another portion of the same mortar was spread briskly as soon as it was made, on oblong pieces of dry and warm tile, and these were immediately placed over a sand bath, where they were gradually heated to about 100° Fahrenheit for six hours, and then to 150° for two hours more, when the mortar was dried thoroughly. I took particular notice of the solidity which it acquired in this hasty drying, and then put the pieces of tile with the adhering mortar into a bottle, stopped in the manner already described, marking down the

gross weight. At the expiration of seven months the whole was found unaltered in weight, and the mortar as easily cut or broken as it was when put into the bottle.

"Exp. 3. Another part of the same mortar was spread whilst fresh on a large tile, to the thickness of half an inch, aud the tile was immediately placed in a tub, in which water was put to the depth of three inches over the mortar, and which was placed in the open air to receive the rain. At different periods I broke the calcareous pellicle which formed on the water and defended it from the air during the first fortnight: afterwards the wind and rain rendered this precaution unnecessary. In the course of six months, the mortar, instead of acquiring any solidity, was deprived of the greater part of its lime and what remained on the tile was not much different from a layer of wet sand.

"Exp. 4. Another portion of the same fresh mortar was spread on a board strewed with slaked lime to prevent adhesion, and placed in the open air, but sheltered from the sun. When this mortar became sufficiently solid, which was on the second day, the pieces were raised, which were about a quarter of an inch thick, and placed upright, fully exposed to the weather, which was about this time dry and warm.

"In seven weeks after this exposure they were indurated to a considerable degree. They resisted a cutting instrument as much as Portland stone does, but not so well any force tending to break them across at once. I then placed them under water as I had done by the former portion of this mortar.

"After they had lain in water four months, I examined them attentively, and found them, if at all altered, to be rather softened than indurated further. I replaced them in the water, to be better satisfied about them, but by mistake they were removed in my absence and lost.

"Exp. 5. Soon after the foregoing parcel of mortar was made I prepared another in the same manner, and spread a part of it on a

tile soaked in lime-water, and placed the tile in the open air, sheltered from the sun and rain; and after it had remained there one month, it was placed where sheltered from the rain only.

"Exp. 6. Another portion of the same mortar was spread fresh on a warm, dry tile, which I placed over a sand bath heated to about 100° Fahrenheit for six hours, and then to 150° for four hours more, at the expiration of which it was solid and hard. The next day they were placed in the open air, exposed to the sun and weather, which was dry and warm for a considerable time afterwards.

"On comparing these two last specimens at the expiration of seven months, and again after six months more, I could easily perceive that the latter was inferior to the former, for it was much more easily cut, and scaled from the tile, and broken.

"Exp. 7. With mortar made the day after the former, of the same materials and in the same manner, and with new bricks, which I had heated almost to redness, and suffered to cool almost to the temperature of my hands, I briskly erected a little wall, half a brick thick, on a stone bench raised for the purpose, and fully exposed to the weather.

"Exp. 8. On the same day, and with the like mortar, and with cold new bricks previously soaked in lime-water, I built another wall equal to the former in dimensions, and placed it in same manner on a stone bench in the open air.

"After nine months, in pulling these walls to pieces, and in divers comparisons of the cement of them, I found that the latter cement adhered better to the bricks, and was harder than the former, insomuch that I had not a doubt about it.

"Exp. 9. In a few days after I had made the experiment with the warm bricks, I considered the walls erected in variable weather, and the fence walls which are wetted frequently and deeply, while new, by rain or by moisture from the ground, and as often dried as quickly: and being desirous to learn the effects of such alternations of wetting and drying, I spread mortar made like those parcels lately mentioned,

on a large tile soaked in lime-water, and as often as it had dried in fair weather, and generally at the interval of three days. In the course of nine months I found it was much less indurated than the specimen made in the same manner, and defended from the rain; it moreover grew green by means of a vegetation which took place upon the surface of it, and which thrived the more as the mortar was frequently wetted, or the tile longer permitted to lie flat on the stone bench already mentioned.

"I have often observed such a vegetation on mortar which I had made a few months before, especially when, in the summer season, I had laid tiles flat on the wooden border of a dust-hole, or when, from want of room to preserve the specimens in, I piled many of them together in a damp corner on the pavement; I likewise saw that when the vegetation took place, the induration did not proceed as it does elsewhere; on the contrary, semi-indurated mortar softened them.

"All these being considered, I was satisfied that frequent wetting or constant moisture, together with exposure to the air, injures mortar to a great degree, if it be not perfectly indurated by great age before it is exposed to such trials, and that the vegetation chiefly depends on moisture.

"Exp. 10. By the kind of analysis mentioned in the 10th section, I repeatedly examined the proportion of the acidulous gas to the lime, in the hardest of the old cements which I had collected, and finding it in the best of them to be, at the lowest, in the proportion of three to five, I rate the quantity of acidulous gas imbibed by good mortar, during the induration of it, to be sixty pounds at least for every hundred pounds of lime.

"Exp. 11. Such mortar as that of the first experiment of this section, was formed into slender pieces, each an inch broad, a quarter of an inch thick, and three inches in length. These were placed in an airy passage, sheltered from the sun and rain, and were turned as soon as they could bear it without danger of cracking, they were then set upright and fully exposed on all sides to the air. On the fourth

day I slid four of the pieces entire into a small wide-necked glass retort, which I set deep in a sand-bath, with its nozzle immersed in quicksilver, which stood cool whilst the charge was gradually heated; in the course of forty-eight hours, to about 75° Fahrenheit, which is under the temperature of incrustations of this kind exposed to the sun in summer; and in the course of forty-eight hours more, was slowly heated to about 100° Fahrenheit, to which degree incrustations are frequently heated by the sun in summer. As the retort cooled, I admitted the necessary quantity of air, and then left it, with the nozzle immersed deeply in the mercury during three months. I then gently slid the pieces out of the retort, after having wiped away a few drops of water which adhered to the vessel in their way, and immediately made the comparison which I shall presently mention.

"Close to the retort, and in a situation where the heat was equal to that described, or nearly so, I placed four other of the pieces above described, on the fourth day after they were made, and encompassed them with sand, but with a free access, and even a circulation of air to them. When the sand bath was cooled, I put these pieces which were thus perfectly dried, into a bottle stopped closely in the manner heretofore mentioned.

"On the seventh day after the pieces were made, also on the twenty-first, and at the expiration of three months, I examined four pieces taken from different quarters of the remaining parcel, and found the quantity of acidulous gas which they yielded to correspond with the degree of induration, and the depth to which it had advanced in them respectively.

"On comparing and examining the pieces dried in the retort and kept three months in it; the pieces dried in the same heat and freely exposed to the air during four days, but afterwards kept in a close vessel; and the pieces which dried and hardened in the free air, without being heated; I found that the first were friable in comparison with the second, and the last were by much the hardest and best.

"As the second, tenth, and eleventh experiments, together with

observations formerly made, show that the induration peculiar tc mortar is not caused by exsiccation; that it is greater as the calcareous matter of cements approaches nearer to be saturated with acidulous gas; that it is retarded or prevented as the accession of acidulous gas is interrupted or obviated; we may conclude that this matter is a principal agent in the induration of calcareous cements, and indispensably necessary to it.

"By observations formerly made, but especially by the comparison of the fifth and eighth experiments of this section, with the sixth and seventh, I learned that hasty drying prevents good mortar from ever acquiring the hardness which it otherwise would have; and that the more slowly the proper water of the mortar is exhaled or absorbed from it, in incrustation or brick-work, the more perfect will be the induration.

"By the first, third, and ninth experiments of this section, compared with the fourth, fifth, and others, and by observations which led me to make these experiments, I discovered that mortar which is not suffered to dry, or which is supplied with moisture as fast as its proper water exhales, does not harden, or hardens only to a small degree by an accession of acidulous gas.

"The fourth experiment indicates that mortar, whose lime has not yet imbibed its complement of acidulous gas, although the mass be considerably hardened, is liable to be injured by soaking in water, if it be pervious to water so freely as these thin pieces were.

"All these experiments and observations conspire to point out the circumstances in which mortar becomes indurated the soonest, and in the highest degree, and operates most effectually as a cement. To this end it must be suffered to dry gently and set, the exsiccation must be effected by temperate air, and not accelerated by the heat of the sun or fire. It must not be wetted soon after it sets, and subsequently it ought to be protected from wet as much as possible, until it is completely indurated; the entry of acidulous gas must be prevented as much as possible until the mortar is finally fixed and quiescent, and

then it must be as freely exposed to the open air as the work will admit, in order to supply acidulous gas, and enable it sooner to sustain the trials to which mortar is exposed in cementitious buildings and incrustations.

"From these considerations we learn other causes besides those already mentioned of the speedy ruin of our modern buildings.

"The mortar made with bad lime and a great excess of it, and debased in watering and long exposure, is used with dry bricks, and not unusually with warm ones. These immediately imbibe or dissipate the water and not only induce the defect above noticed, but, as the cement approaches nearer to dry, whilst it is liable to be disturbed by the percussions of the workmen, render it more nearly equivalent to a mixture of sand and powdered chalk.

"But in order to make strong work, the bricks ought to be soaked in lime-water, and freed from dust, which in common bricklaying, intercedes between the brick and mortar in many parts. By this method the bricks would be rendered closer and harder; the cement, by setting slowly would admit the motion which the bricks receive when the workman dresses them without being impaired, and it would adhere and indurate more perfectly. The same advantages would attend the soaking of bibulous stones in lime-water, and the use of grouts, provided this were made with good lime, sand and lime-water.

"In plastering, the workmen always brush away the dust, and wet the wall on which they are to lay the cement, because it will not otherwise adhere. From what has already been said, it is manifest that this ought to be done with lime-water, and repeated as long as the wall is thirsty.

"To perceive more clearly how much our slight buildings are weakened by the agitations and percussions to which they are exposed, first in erecting the walls, and setting the timbers, and then driving those wedges (plugs) to which they fasten the wainscot, cornices and other ornaments, we must observe that the accession of acidulous gas to mortar, was found to contribute nothing to the strength of it,

when it entered the composition before it was finally fixed in a quiescent state, and a little experience is sufficient to teach us, that the same matter which assists in the induration of mortar, never serves to repair the fissures, or solution of continuity between the bricks and cement which happen after it is set. When mortar is set, and before it is indurated, it may easily be severed from the bricks and crumbled, and for want of softness it cannot bend into the fissures, or resume its former condition in any time. Therefore, by heavy blows, and in wedging, our walls must be greatly weakened, and the more, as the houses are slight, quickly built and slightly finished."

Experiments on Old Cements, authorising the proportion lately recommended of lime and sand.

"To discover the quantity of lime and sand originally used in many hard and old cements, which was found by a previous analysis to consist of lime, and sand or clear gravel, I break a pound of it into small fragments, but not into powder, and with diluted warm acid I dissolve and wash away the calcareous part from the gravel or sand. I measure the acidulous gas obtainable during the solution, and knowing the weight of any quantity of it, in any temperature or weight of the atmosphere, I substract this weight of acidulous gas and that of the sand or gravel, from the whole weight of the mortar, and state the residuary weight as that of the lime originally employed, knowing that it could not have made so hard a cement, if it had not been so far burned as to retain very little acidulous gas. I did not adopt this method of examination before I found it to exhibit the lime and sand of my oldest and hardest cements, in the same proportions in which I had mixed them.

"By this kind of analysis, and by other trials, I found that the quantity of lime in old cements made with clear, sharp sand, and noted for their hardness, was much less than is now commonly used in mortar, and that in the hardest of them, it was very near to that

which my experiments indicated to be the best. By sharp sand I mean those whose grains are bounded by flat surfaces. Thus I found the inferences made from my compositions to be authenticated by long experience so far as they related to the proportion of lime and such sand."

The foregoing practical experiments of Dr. Higgins, undoubtedly prove, 1st. That the value or quality of lime for mortar depends upon its freedom from acidulous gas; 2d. That it should be well or perfectly burnt; 3d. That it should be used immediately after it is burned; 4th. That its quality is greatly debased or deteriorated by exposure to the atmosphere; 5th. That the nature or quality of the sand employed is important in the composition of mortar, and that when used should be perfectly clean and free from any foreign or objectionable matter; 6th. That sand of a mixed size or gauge is preferable for general purposes; 7th. That sea sand, or any other sand which contains saline impregnations, is objectionable for mortar; 8th. That the best proportion of lime to sharp, clear sand, where strength and durability are concerned, is that of one part of lime to six or seven of sand; 9th. That the water used to amalgamate the other ingredients of mortar should be pure: sea or any salt water, or any that are impregnated with mineral or chemical proportions are not only objectionable but injurious; 10th. That as little water as possible should be used in the preparation of mortar, and that an excess thereof, and especially a second application, after the mortar has been once properly made, is debasing to the mortar, as it dissipates the cementitious properties of the lime, and leaves a large residuum of acidulous gas, which is imbibed or absorbed by the lime; 11th. That lime-water is far preferable to crude water for making mortar, as the solution of lime has the effect of disengaging or discharging the acidulous gas from the water; 12th. That the perfect induration of mortar depends upon a moderate temperature and a protection from rain, frosts, &c., and that (*cœteris paribus*) those mortars are the hardest and most durable that require the longer time to dry; 13th. That the bricks

should never be used when warm, and that they be free from dust, never used in a dry state, but should be previously wetted or soaked with water, lime-water being preferable; 14th. That brick or stone work when once laid, should be disturbed as little as possible, for when a joint of mortar is broken, after it is once set, it becomes very problematical whether it will ever properly unite again.

Having now described the several ingredients forming the composition of mortar, and exhibited sundry experiments thereon, with their results and inferences, from the inquiries and labors of the celebrated Dr. Higgins, whose work and reputation upon this, stand preëminently and deservedly high, and who ranks as one of the chief authorities upon the subject, we shall in due course proceed to lay before the inquiring reader, the mode of preparing the several ingredients of mortar, their combination and application, interspersing our remarks with the opinions and practice of other professional men of note, who have recorded the issue of their labors for the benefit of the present and future generations; after which, we purpose to complete our notice of other experiments of Dr. Higgins upon the effects of combining sundry foreign matters in the composition of mortar or cements for particular purposes, to which will be appended some account of the cements used by the ancients; also an account of hydraulic cements, their nature, properties, use, combination and application, together with the experience, opinions, and experiments of some of the first authorities thereon; and the whole to conclude with a detailed account of the lime-kiln, and various modern methods of burning or preparing lime, &c-

Such being the "programme" of the entertainment now contemplated, we will proceed to perform the several "parts" in their consecutive order, trusting the "finale" will be satisfactory.

On the Preparation of Common Mortar.

The Lime when perfectly prepared or burnt in the kiln should be speedily withdrawn, and packed for transportation to its intended destination, in sound casks or air-tight vessels well closed down, and should be kept entirely free from all moisture; and when received by the builder should be deposited until required for use (which should be as early as possible) in a shed or other dry building, or if left out of doors should be closely covered with a tarpaulin, or boards, and each cask should be unheaded or opened only as required.

Lime in this state is termed *caustic or quick lime*, and in order to make it fit to be incorporated with the other ingredients it must be reduced to "hydrate," a change which is effected by the application of water, which process is termed "slaking" and after which operation the lime is called *slaked lime.* Of this operation, there are three methods in use. The 1st. and most usual is by pouring or throwing the necessary quantity of water over the lime after it is spread out into a shallow heap, surrounded by the whole or a portion of the sand with which it is to be incorporated. 2dly. By immersion, or plunging the lime when deposited in a basket or other suitable receptacle for a few moments into water until the surface lime begins to effervesce or boil and then turned out into heaps to afford time and opportunity for the slaking to be completed. And 3dly., by mere exposure to the atmosphere, the lumps of lime having been previously broken up to about the size of a pigeon's egg, or somewhat smaller, so as to secure a more speedy and effectual calcination of the whole, but this operation must not be performed in wet weather, nor in too damp an atmosphere; it must be carefully watched, and so soon as the slaking is complete, the quick lime must be immediately used or deposited in close casks till required. This method is seldom adopted except for plasterers, who consider lime so prepared preferable for their work, as it is said to make the lime stronger. This mode suits *fat* limes (such as slake freely) better than poor limes. Lime slaked by the second process will

keep well for months in a dry, sheltered spot. But in every case where water is employed for slaking lime or mixing the mortar subsequently, care must be taken not to "drown" the lime for the reasons before explained, and also not to go to the opposite extreme, but to put the *quantum suff.* at once, which is usually computed at about one and a quarter of the weight of the lime, or from four to five gallons to a cubic foot of lime, which weighs upon an average from 28 lb. to 35 lb., for if the water be applied tardily or sparingly, the lime will be benumbed, or imperfectly calcined, and gritty.

But the exact quantity of water required will be proportionate to the nature and quality of the lime—the fat or richer sorts will require or absorb more than the lean or poorer sorts, so that in this matter no absolute or definite rule can be laid down, but the architect or builder must exercise his observation and judgment—always bearing in mind that it is most essential that mortar should be used fresh, that it will consequently be necessary to apply a sufficiency of water at once, so as not to expose the lime unnecessarily long to the atmosphere.

Limes become *effete* (difficult to slake) after much exposure to the air, so that speedy calcination is important to their subsequent use or value.

Limes, when slaked, increase considerably in bulk and weight by their absorption of both moisture and air, as hath before been alluded to, and which increase varies in different specimens of lime.

The slaked lime must be passed through a seive or screen, the meshes or orifices of which should be small, not exceeding one hundredth part of an inch, so as to give passage only to the *powdry* particles of the lime or that which is perfectly calcined, leaving all the core or indissoluble portions of the lime behind, which must be thrown out; and if, after a further addition of water and lime, it should prove obdurate, and will not slake, it must be abandoned altogether; however, this refuse will be found serviceable to use in concrete, or to fill round the sides of walls, piers, drains, &c., or to lay under floor

next the earth, where it would check damps by partially absorbing any rising moisture. The operation of screening the lime is sometimes performed before its admixture with the sand, and at other times with it; of these two methods we prefer the latter for the following reasons, viz.: because it effects a saving of time, and because it insures a better and more equable amalgamation of the ingredients, and because the lime is thereby not so much exposed to injury from the atmosphere.

Upon the perfect completion of the above-described operation, the combined mass should be spread out in the form of a hollow cone, and the final complement of the aqueous fluid should be speedily but uniformly added; the whole mass being at the same time effectually stirred up and about, to promote a proper combination thereof; or what is better, the mass should, so soon as it is brought to a proper consistency, be passed through a "pug mill," which is a machine well known, and employed in the preparation of clay for the manufacture of bricks; but where this desideratum cannot be obtained, it should be well-tempered with wooden beaters, and also well-turned over and incorporated together, as it is also very important for the solidity of the work for which it is to be used, that the mortar be well mixed and quite uniform throughout.

Mortar should be prepared of a medium consistency, not too "tough," that is, not too *dry*, nor yet too "short," that is, not too *wet*—for in the former case the beds and joints will be rigid and difficult to regulate, from the absence of sufficient moisture, and what there is will be speedily absorbed by the brick or stone, and the mortar will indurate too speedily, and in the latter case, the joints will *settle* too much, and the quality of the mortar be deteriorated.

The induration of mortar is dependent upon its due absorption of carbonic acid gas from the atmosphere, and it is necessary in order to effect the re-union of carbonic acid with the lime, that the latter should have received, previously, not less than one-third its weight of water, and which is proved by the fact that if dry-slaked lime be put

into a jar or vessel of carbonic acid alone, there will be no absorption whatever.

Mortar, stuccoes, or cements, prepared from ill-burnt lime, continue soft and dusty for a long time after being made; whereas, when they are compounded of well-burnt and slaked lime, they readily imbibe the carbonic acid and soon become thoroughly indurated.

Rich limes emit a strong hissing noise and great heat during the process of slaking, but the poor or meager limes, which nevertheless are the most valuable, undergo the operation with less apparent excitement; and in proportion to the extraneous or foreign matter which they contain, and with some varieties of hydraulic limes, no visible effect will be observable in them until after the lapse of several hours.

The purest limes require the largest proportion of sand, and require the most water in slaking, and harden in less time than the common limes.

Hydrate of lime, or the powdered state of lime produced by slaking whilst in a damp state, soon falls away and is dissolved in water, and the same result is produced by alumina, manganeze, silica, &c., but not to so great an extent.

In the before-mentioned experiments, Dr. Higgins determined that the best proportion of lime and sand is one measure of the former to six or seven of the latter; but in England the tradesmen usually combine one hundred and a half, that is, 150 pecks, or 37½ striked bushels of chalk-lime with two loads of sand, that is, 60 bushels of sand; and with the like quantity of stone lime they usually put two and a half loads of sand, or 75 bushels, which are very erroneous proportions, as the sand experiments clearly show, and as our own experience has often testified.

The above-mentioned quantities are each sufficient to do a rod of brick-work, which is equal to 272¼ feet of one and a half brick thick, or 408½ feet of one brick thick; to this standard the calculation of all brick-work, of whatever thickness it may be, is reduced, and by

this, the architect, in his specification of works, usually limits or determines the quantity of lime and sand to be used.

Various substances are sometimes added to mortar to increase the tenacity, and they impart thereto the principles of *hydraulic* cements to a greater or lesser degree.

These chiefly consist of burnt clay, ashes, scoriæ, iron scales and filings, pulverized broken potter's ware, bricks, tiles, &c., all of which are very useful for mixing with lime or mortar to increase their hardness, but these must be very pure and dry, and reduced to a fine powder before being mixed with the lime. To enable lime to harden by the absorption of carbonic acid, it must be divided as minutely as possible so as freely to admit the air, and for which purpose these substances are available. Any of these compositions are very useful for the purpose of bedding, chain-bond, wall-plates, templates, common bond or bearers upon walls, instead of *lime mortar*, the properties of which are highly injurious to wood, and on that account ought never to be brought into close contact therewith.

Common mortar of ashes is prepared by mixing two parts of fresh slaked lime with three parts of wood ashes together, and when cold, to be well beaten, in which state it is usually kept for a considerable time; and if beaten two or three times previous to using it, will be found to improve by keeping. In resisting the alternate effects of moisture and dryness, this mixture is by some persons thought to be superior to terras mortar, but not nearly equal to it when applied quite under water.

We will now proceed to quote further from Dr. Higgin's work:—

Experiments showing the Effects of Finest Sand and Quartoze Powder in Mortar; Observations on the finest Calcareous Cements; Practical Precepts.

"The last-mentioned notion led me to suspect, soon after the foregoing experiments were made, that although the fine Thames sand

made better mortar than the coarse sand or rubble afforded, the mortar will not always be the better as the sand is finer, however sharp it may be. I therefore procured a large quantity of the very fine pit sand, used in London under the name of "house sand." I washed away the clay with which it abounds, and dried it. Viewing it when thus cleansed, with a lens, I estimated the size of the grains to be, at a medium, about one-ninth of that of any fine Thames sand; this I shall call, *finest sand.* At the same time I was favored by Mr. Bentley, the ingenious manufacturer of ornamental Staffordshire ware, with the necessary quantity of the fine powder of calcined flints, which is prepared for his manufactory. With divers mixtures of these with lime-water and lime, in a variety of proportions, and with each and both of these ingredients blended with coarse and fine sand, lime, and lime-water in similar proportions, I made a great number of specimens of mortar, which I tried in the manner already described; and noting my observations on them I found the following to be the most eligible, for the concise recital intended in this essay :—

"1st. Mortar containing the quantity of lime necessary to the plasticity and other desirable properties of it, or a greater quantity of lime, is the more liable to crack in drying, as the sand of it is finer.

"Mortar made with this finest sand and lime, does not grow so hard, or resist fracture so forcibly, as that made with the fine Thames sand and lime, in the same proportions, or any others nearest to these. But the former mortar, when composed of about six parts of sand, one of lime, and the necessary quantity of lime-water, and slowly dried, becomes much harder than many of the calcareous stuccoes commonly used by the plasterers.

"3d. Mortar composed of lime, fine Thames sand, and the finest sand, is worse as the quantity of the finest sand is greater, and this holds true in every tried proportion of the sands and lime.

"4th. Mortar consisting of lime, coarse Thames sand, fine Thames sand, and finest sand, is the worse as the quantity of the latter is greater, when the comparison is made between it and the cement

made with the same quantities of lime, and the best mixture of coarse and fine Thames sand.

"5th. Mortar made with flint powder, lime, and lime-water, in any proportion, is more liable to crack in drying, than mortar composed of any sand and lime; it is moreover incapable of hardening to so great a degree, whether it be tested by a chisel, or by breaking it across. But mortar made with about five parts of flint powder, one of lime, and the necessary quantity of lime-water, is nevertheless preferable to any stucco now used for inside work, for the finishing coat, because it has a more lively whiteness, and assumes a finer surface, which I think might be made to imitate that of marble; it requires, however, to be dried very slowly.

"6th. Mortar made with coarse Thames sand, fine Thames sand, flint powder and lime, or with fine Thames sand, finest sand, flint powder, and lime, or with the finest sand, flint powder and lime, is worse as the quantity of flint powder is greater, relatively to that of the sand.

"Upon the whole it appeared, that the finest sand is injurious in mortar which is exposed to the weather, and that flint powder is still worse, but that this last may be advantageously used in composing stucco for inside work, in which a fine texture, pleasing color, and smooth surface are preferred before extreme hardness, and in which the drying may be regulated so as to prevent the incrustation from cracking.

"Instead of resting satisfied with the bare discovery of the fact, that very fine sand or quartoze powder is incapable of making so good a cement as may be formed with coarser sand, although fine Thames sand and lime make a better cement than can be composed with the coarse sand and lime, and that the mixture of the very fine sand, or siliceous powder, with the Thames sand, is rather injurious than useful, although the mixture of the coarse Thames sand with the finer, is better for mortar, than either of them, unmixed. I took a great deal of pains to learn the cause of this, in order to confirm or correct the

foregoing notions, and render the precepts which flow from this fact, the more satisfactory.

"By sorting my finest sand into divers parcels, in sifting it through different sieves, by measuring the meshes of these, and by viewing the grains of each parcel ranked closely on a scale, I perceived, more clearly than I had done before, the roundness of this sand; I moreover found that the grains of the coarsest parcel were, at a medium of their respective bulks, upwards of sixteen times larger than those of the finest parcel; the grains of the other parcels being of divers intermediate sizes. As this sand therefore has every advantage attainable by the admixture of coarse and fine grains, and every disadvantage resulting from the smallness and roundness of its grains, I learned the reason why the defects attending such fine round sand in mortar are not corrected by any mixture of coarse sand. How these defects are induced by the finest sand and flint powder, we may conceive in the following manner:—

"Having already shown how the roundness of sand tends to render the mortar made with it defective, I may, without any further illustration of this matter, reckon on this figure of the grains of finest sand, as one cause of the imperfection of the mortar in which it is used.

"There is nothing to prevent the laminæ of lime-paste, which intercede the grains of finest sand, from being as thick, in the mass of mortar made with it, as they are in mortar made with coarse sand, but they are likely to be thicker in general, as the faces of the finer grains are rounder.

The number and extent, moreover, of these laminæ, must be greater, in the sum, in the finest sand, than in the coarser, and it is for these reasons that more lime-paste is required to make mortar with the former than the latter, since the mortar is not formed until the paste developes every grain and fills the interstices. In this view of the subject we discover another cause of the defect lately mentioned. If we use lime with a sparing hand it will not extend be-

tween all the grains or fill the spaces; we find the mortar too "short" whilst fresh, and it is as defective in strength when indurated as it is deficient of the cementing matter. When we use the necessary quantity of lime, the calcareous matter bears a greater proportion to the quartoze grains, in this finest mortar, than in the coarser, and this renders the former defective, according to the principles of aggregation already expressed.

"A third cause of the imperfection of mortar, made with finest sand, or containing a larger quantity of it, appears on the consideration of the quantity of lime.

"We have repeatedly seen that mortar contracts the more in drying, and is the more apt to crack, as it contains a greater quantity of lime-paste, and as the finest sand requires an extraordinary quantity of the paste to form it into mortar, the aggregate of such a cement is likely to be impared by fissures, although they do not always appear, by reason of their smallness.

"Other causes of the experienced imperfection of fine mortar might be added, which have no relation to the figure of the grains of sand, or the quantity of calcareous matter, but to avoid an excess of theory, I forbear to mention them, and shall only add a conjecture concerning the finer cements.

"When a cementitious mass, like mortar, is cut with an edged instrument or broken across, we may observe that the fracture happens in the shortest line, along the laminæ of the weaker cementing matter, and seldom or never in the shorter right line passing through the harder grains and the cement alternately, although the impressed force tends to cause the solution of continuity in the shortest or in a right line. By the principle of mechanics, the resistance to such forces is greater (*cœteris paribus*) as the line of fracture is longer, whether it be straight or winding in any course; and it is for this reason that a wall built with any large stones, is less liable to crack, although the foundation should fail near one extremity of it, than a brick wall built with the same kind of cement on the like ground; or that a wall,

whose bricks are jointed in the present fashion, is more secure from cracking, that that which should be built, on the like infirm ground, with the same kind of bricks standing over each other, not jointed, but with their sides and ends flushed, as the workmen express it.

"As cements are cut and broken in the direction of the cement, and not in the shorter line, as the cracks in ill-founded walls run winding along the joints, instead of going in the shortest course, through the bricks and joints alternately, and the resistance of such cementitious masses, estimated by mechanical theory, is greater, as the line of fracture is necessarily elongated, by the stronger aggregation of certain parts of them. I am inclined to think that calcareous cements made with lime, and quartoze powder will always be found weaker under trial by the chisel or by fracture, as the quartoze sand or powder is finer, because the line of fracture, which takes the course of the cementing matter, is shorter, in any equal depth of such masses, as the hard quartoze grains are finer and rounder.

"As flint powder consists of exceedingly fine grains of silicious stone worn to roundness in the grinding, what has been said of the finest sand is sufficient to show why the cements which contain flint powder are the worst of all those we have mentioned.

"The customary method of washing sand, even for stucco, which is to be exposed to the weather, consists in passing it through a sieve, by a circular horizontal motion of it, in a tub filled with water, which flows over and carries away with it any light matter which can be long suspended in water, as fast as the sand runs through the sieve into the vessel. But this process is inadequate to our views, because the finest sand subsides along with the best, and those in the precipitation entangle and carry down with them a great deal of finer powder and dirt. Where such a method must be pursued for want of other utensils, or through the scarcity of water, the sand ought to be agitated again in small parcels, with a part of the water which has cleared by subsidence, and immediately after the agitation, the muddy water ought to be poured off before the light parts have time to subside in it.

But the useful part of sand is more effectually freed from the finer and noxious parts, by sifting it in streaming water, whose current is to be so managed that it shall carry away the mud and the sand which is too fine, whilst the better part subsides in a proper receptacle.

"In the subsequent pages I purpose to show the integrant parts of gravel, and their several properties in mortar; for the present purpose it will be sufficient to observe that the gravel commonly employed in building consists chiefly, after it is screened, of rubble, coarse sand, fine sand, and finest sand, similar to those used in our experiments. This is obvious on the bare inspection of it, and leads us to discover another cause of the weakness of our modern cements, in the composition of which no other precaution is used, respecting the gravel, except to separate the stones and coarsest rubble from it by screening.

"When it happens that the screened gravel contains more than a certain quantity of rubble, relatively to that of coarse and fine sand, similar to those described, the mortar made with it, must, according to our experiments, be defective. It will be so likewise, whenever the coarse sand of it predominates over the fine sand, to a greater degree than that which was found consistent with the perfection of mortar; and when the quantity of finest sand happens to be considerable in gravel, the mortar made with it must be faulty in a greater degree.

"Now supposing the gravel to be freed, by the screening, from everything more injurious than finest sand and quartose powder, we perceive that the artist who is ignorant of the advantages of sizing his gravel, and uses it in its native state, as chance presents it, has the odds greatly against his making good mortar, although he may sometimes do it, without knowing the reason, as we shall find hereafter, for his chance is, that the native gravel shall consist of coarse and fine sand mixed in the proportion of three to four, or of the rubble, coarse and fine sand mixed in the proportions above recommended; and that it shall contain little or no sand like our finest sand, but the chances against him are as numerous as there are other distant proportions of

rubble, coarse and fine sand in gravel, and as the kinds of gravel used are, which contain the finest sand, or still finer quartoze grains in efficient quantities.

"In great cities where gravel cannot be procured so cheap as the rubbish of old walls, which the workmen lay in the streets to be ground to powder by the passing carriages, they use this rubbish, screened, in the place of sand or gravel, in making mortar. It consists of the gross powder of bricks, and of mortar indurated, as much as bad mortar can be, by time, and some builders affirm that it is better than sand or gravel for mortar. It is certainly eligible when the price is chiefly considered, in any other view, it is not so.

"From my past experience, I judged the calcareous powder of an old cement, and that of the bricks, to be a brittle, perishable and weak substitute for grains of sand, and the quantity of dust in such ground rubbish, to be highly injurious, but as the opinion of the workmen was against me, I made some trials of it.

"I found that less lime was required to make fat mortar with this ground rubbish, than with my best mixtures of sand, which is no small recommendation of it in certain jobs, and is owing, in my opinion, to the ground calcareous part, which, so far as it is finely powdered, is equivalent to whiting, but the mortar made with the rubbish appeared, in every stage of induration, and in every comparison, except that of plasticity, to be greatly inferior to that made with mixed sand and lime in the same proportions.

"If the workmen would confine their opinion to the comparison of such rubbish mortar, with that in which clayey gravel is used, or with the cements made with the ashes and ordure of the town, dug out in preparing foundations of houses, in those places which were formerly receptacles of such matter, they might maintain it on divers grounds which will be examined hereafter, but otherwise it is erroneous."

EXPERIMENTS MADE ON A LARGER SCALE WITH OUR BEST MIXTURE OF SANDS, LIME-WATER AND LIME.

"At a subsequent period, I repeated a great number of the foregoing experiments, particularly those which exhibit mortar in the improved state to which I had brought it; and finding my former observations to be true, when the circumstances were not varied, I resolved to try my best cements in larger quantity, and in other circumstances.

"I applied them in the way of stucco, on the brick walls of houses in different aspects, but chiefly in that of the meridian sun; covering a square yard at least with each specimen, after I had repeatedly wetted the wall with lime-water.

"By these trials I found that mortar made with four parts of coarse sand, and three of fine, wetted with lime-water, and beaten up with one of my lime, slaked with lime-water, although it could be easily spread on a horizontal plane, or used in building with bricks, was rather too 'short' for plastering on the perpendicular surface of a wall. It might, however, be laid on in small successive portions, by a dexterous management of the trowel, and especially by sliding the tool on it upwards.

"When the weather continued temperate and dry for eight or ten days after the incrustation was made, and no great quantity of rain fell for three or four weeks afterwards, this stucco answered my expectations, for it did not crack in the least, and in three months was almost as hard as Portland stone at the surface, where the induration first takes place for the reasons formerly mentioned, but it was too coarse to represent a fine grained stone.

"Having made two pieces of incrustation of this kind, on the same wall, and knowing that calcareous cements cannot harden so soon as necessary in outside stuccoing, unless they be pervious to acidulous gas in which case they may drink in water likewise. I frequently wetted one of the pieces, in about three months after it was formed, with

lime-water, expecting that the calcareous matter of it would crystallize in the cement, and render it harder and closer. I was not disappointed, for, in the course of a month I found this piece of stucco harder and closer than the former, and at the surface as much superior in these particulars to Portland stone, as the other was inferior to it. I have since found that lime-water has not this effect, if the incrustation be wetted with it before it is quite dry and indurated slowly, to vie with Portland stone in that kind of strength which is tried by grinding Portland stone on it, or scraping it with a chisel, for any other trial of incrustations is unfair, until the induration has proceeded equally throughout the mass.

"When the incrustations made of the same cement, were wetted by rain in two or three days, or sooner, after they were applied, and especially when the wind blew the rain forcibly upon them, they were sensibly injured, for they never afterwards looked or hardened so well as the former specimens of stucco.

"In these particulars the large incrustations agreed with those made on tiles, but the same agreement did not appear in the incrustations which I had made with the same composition on a wall which fronted the meridian sun, at a time when the weather was very hot, for these showed a few slender cracks in the course of three days. When in the same situation and weather, and on a coarse stucco of this kind, I spread in about two hours, after it was laid on, a thinner coat of cement made with finer sand in order to represent a finer grained stone, the incrustation consisting of these two layers cracked more than the former.

After many repetitions of these experiments in the hottest weather with the same result, I perceived that the trials of such cement on tiles are not so severe as those to which they may be exposed sometimes in incrustations on walls. In the latter case, the stucco is very unequal in thickness, for in the hollow joints and depressions of the bricks it is near an inch thick, when over the prominences it has not more than one-eighth of this thickness; and as it dries soonest in the thin

parts, the unequal contraction seems to be the cause of those cracks, which would not happen to the same cement laid on the flat surface of a tile; it seems, moreover, that such a composition may more easily contract in drying, without cracking, as the crust is made narrower or less extensive. But I impute the cracking chiefly, to the foregoing unequal contraction, accelerated not only by the heat of the sun and the wall, but by the thirsty bricks, for if we form our judgment according to the quicker or slower progress of the exsiccation, and the stiffness which the cement acquires in the act of spreading it on the brick wall, and the wetting of this last, superficially with lime-water, is not equivalent to steeping the tiles for a few minutes in the same liquor.

"When with a view of preventing fissures, I stuccoed a part of the same wall (wetted with lime-water) with cement containing the mixed sands and limes in the proportion of fifteen to two, in the same kind of weather, I found the difficulty and waste in applying it greater than in the former instances, and that it was defective in strength and closeness for want of lime, although it did not crack. When through distrust of my former experiments, I used more than one-seventh of lime, the cracks were still larger and more numerous.

"To guard a recent incrustation from the rain, and to secure it from cracking in the circumstances last described, I proposed the expedient of hanging sail-cloth on the cornices and scaffolding, but the expense of this measure, and the danger arising from it in windy weather, were strong objections. Embarassed by this unexpected difficulty, I resolved to change my ground, and try what might be done by a new series of experiments, in which I intended to use every known cheap substance, whether it could be reasonably supposed to have any considerable effect towards securing a recent incrustation against the above-mentioned impressions of rain or hot weather, or could be suspected of rendering the stucco defective. I prosecuted this inquiry with great alacrity, because I was certain that, although I

should fail in the attempt towards improvement, I should learn how in future to avoid those things which being naturally blended in certain kinds of lime-stone, sand or water, tend to render the mortar made with them, faulty. I had already conceived a notion, which I shall submit before I conclude, concerning the excellence of some ancient cements; but lest I should be misled by it, I proceeded in all my experiments which I am to relate, on the supposition that the excellence is owing to some matter accidentally introduced in the materials which the ancients found in the districts contiguous to the most durable cementitious works, or designedly blended with their mortar."

Experiments showing the integrant parts of Gravel, the choice and preparation of it, and the effects of Clay, Fuller's Earth, and Terras in Mortar.

"On inspecting different kinds of gravel used in London, and in divers parts of England, in making mortar, I observed that they all contained some clay, and that this was generally colored with martial matter. In consideration of the frequency of which matter in mortar I made it the first subject of my present inquiry.

"By the art already described, I sorted three bushels of screened gravel dug up near Portland place, in Marylebone parish, into five parcels; one equivalent to our *rubble*, another to *coarse* sand, another to our *fine* Thames sand, another to our *finest sand*, and the remainder was set aside as *clay or bolar earth.* I dried all these, and reduced the lumps of clay to an impalpable powder.

"Having treated divers other specimens of gravel in the same manner, I found that gravel, freed from the larger pebbles, may generally be considered as a native mixture of rubble, sand and clay; and that when the clay is washed out, the residuary parts of different kinds of gravel differ in size, sharpness, color, and hardness, those being the hardest which consist chiefly of quartoze matter. Judging of gravel according to the precepts derived from my trials of sand, I

rank that dug in Marylebone amongst the better kinds of gravel, and used no other in mortar.

"After a great number of trials of cements made with my best chalk-lime, lime-water and the gravel, or certain parts of the gravel, and applied on tiles, and on a wall, I found that those made with the coarse and fine sand of the gravel, separated from the rest of it, and mixed in their native proportions, were the best; that those made with the rubble, coarse sand, and fine sand mixed in their original proportions, but containing no other part of the gravel, were the next in hardness, and the other desirable qualities; that those containing all the parts of the gravel, except the clay, in their native proportions, differed in nothing that I could discover from these last, for the finest sand of this gravel was not a fiftieth part of the mass of it; that those containing the rubble, sands and clay, in the same proportions, and those made with the unwashed gravel, appeared on close examination to be the worst of all these, and those containing the native, unwashed gravel, mixed with twice its proper quantity of the clay of such gravel, showed most clearly that clay is highly injurious, by disposing the mortar to crack in drying, to soften in wet weather, and to moulder when the quantity of clay is one-eighth of that of the sand, but in much smaller quantities it only prevents the cement from acquiring the hardness peculiar to good mortar, and consequently disposes it to perish in a few years.

"With my best mixtures of sands, lime-water and lime, I blended fine fat tobacco-pipe clay, in different proportions, and exposing these specimens, I perceived that the effect of the clay is greater as it is purer and fatter; the specimens in which the quantity of fat clay was one-seventh, or one-eighth of that of the sands, mouldered early in the winter like marl.

"These appearances were not altogether unexpected, for in experiments formerly made with a view to the improvement of fire-vessels, I had observed that clay adheres but weakly to any hard bodies, however slowly it is dried on them, and that masses composed of clay and

sand in divers proportions, never acquired any considerable hardness by the mere drying and exposure to the air. It was not, therefore, likely that clay should add to the strength of mortar; but as dried clay greedily imbibes water and swells with it, and in drying, contracts greatly and cracks, if anything prevent it from contracting equably; and as marl-stones, which consist of clay and calcareous earth, moulder in the weather, it was to be expected that clay would be hurtful.

"These experiments point out another cause of the defects of the common mortar, and show that the gravel or pit sand to be used in any valuable building ought to be freed from the clay by washing, which will be found a very cheap operation, even in cities, if the water which carries off the clay be directed into a place where it may be depurated by subsidence, for repeated use; they likewise direct us in the examination and choice of these, and show that the viler kinds may be made equivalent to our best mixtures of Thames sand, or nearly so, by washing or sorting, and then rejecting the excess of rubble, or fine sand.

"I must observe, however, that some kinds of gravel cannot be made fit for mortar by this process, for the grains of them, which resemble those of rubble and coarse sand, consist of smaller grains cemented by clay, which is so far indurated that it cannot diffuse itself in the water speedily.

"*Fuller's earth* tried in the same manner was found to operate in the mortar like clay in every respect, as I might have presumed, except that the former was less injurious than the clay, when the quantities of them were equal.

"*Terras*, which is a volcanic production consisting chiefly of clay and calx of iron, indurated together, when it was ground to an impalpable powder, produced the effects of Fuller's earth, in mortar the more sensibly as it approached nearer to be one-seventh of the quantity of sand. The coarser powder of terras has the same effect.

"A mortar made of terras powder and lime, was used in water

fences by the Romans, and has generally been employed in such structures ever since their time. It is preferred before any other, for this use, because it sets quickly, and then is impervious to water, whence some people hastily conclude that it is the best kind of mortar for any purpose. But by experience I know that mortar made of lime and terras powder, whether course or fine, will not grow so hard as mortar made with lime and sand, but on the contrary is apt to crack and perish quickly in the open air. The efficacy of it in water fences is only experienced where it is kept constantly wet, and seems to depend upon the property which the powder of terras has, in common with other indurated argillaceous bodies, and especially the boles (but in a higher degree), of expediting the crystallization of the calcareous matter, by imbibing the water in which it is diffused in the mortar, and of swelling during the absorption, so much as to render the cement impenetrable to any more water; it seems also, that an acid of the vitriolic kind, which is contained in terras, as well as in boles, contributes to the speedy setting of this cement, by reducing a part of the lime to the condition of gypsum."

Experiments showing the effects of Plaster-powder, Alum, Vitriolic Acid, and of some Metallic and Earthy Salts and of Alkalies in Mortar. Practical Inferences.

"In my best mixtures of coarse and fine Thames sand, with one-seventh, and with larger quantities of lime, I tried the gypseous powder of which *plaster-of-paris* is made, and found it to be injurious in proportion to the quantity of it. The particular effects of gypsum in mortar were such as might be expected in consequence of our knowledge of the saline nature of it, gypsum being in a compound of calcareous earth and vitriolic acid, which is soluble in water, not so freely as neutral salts, but rather like lime, it disposed the mortar to set faster than it could be applied in stuccoing; it contributed very little to the plasticity of it, and the cement was the more apt to soften

in wet weather, and to perish in time, as the quantity of plaster-powder in it was greater. The greater quantity tried was only one-seventh of that of the sand.

"*Alum* was found very injurious. The acid of alum formed silenite or gypsum with a part of the lime, and thus operated like gypsum or plaster-powder, whilst the earth of the alum induced the imperfections which attend the use of clay. The greatest quantity of alum used was one part in ten of the best mixture of sand and lime, and this specimen mouldered, in nine or ten months, like marl.

"*Vitriolic acid*, which formed silenite or gypsum with a part of the lime, produced the effect of a quadruple quantity of plastic powder.

"*Vitriols of lead and tin*, being decomposed by the lime, operated like smaller quantities of vitriolic acid. Martial vitriol or copperas had the same effect, and induced an olive color, which was soon turned to that of rust.

"*Vitriol of zinc*, or white vitriol, and Epsom salt, did not dispose the mortar to set hastily, nor injure it in any particular discoverable during the application and drying of it, for these vitriols are not easily decomposed by lime; but afterwards I perceived that they impeded the induration of the stucco, and disposed it to suffer by the weather, the more as the quantity of either came near to be one-tenth of the quantity of sand.

"*Vitriolated tartar*, Glauber's salts, and the salts which are found in most of our waters, such as sea-salt, nitre, marine calcareous salt, calcareous nitre, and that composed of magnesia, and marine acid, were found, like Epsom salt, to injure the best mortar; so were caustic mineral alkali, caustic vegetable alkali, and liquor silicum. Caustic volatile alkali, which soon exhales by reason of its volatility, had no sensible effect, I did not try argol, or mild alkalies, because they reduce the lime to whiting, neither did I use any acid which forms a very soluble salt with lime, for obvious reasons.

"Knowing that the lime which has been employed by soap-boilers

to render their barilla and pot-ash, *caustic*, contains,(even after the repeated elixations,) a little alkali and vitriolated tartar, blended with the calcareous earth, and that the greater part of this last is restored to the condition of chalk, by the acidulous gas imbibed from the alkaline salts; I had, in consequence of the foregoing experiments, sufficient reason to presume that this refuse matter of soap-boilers cannot answer the purposes of lime, or improve our mortar. But as a pretence to the contrary is made by some, and as its cheapness is a temptation towards the use of it, I resolved to decide this question by direct experiment.

"After trying in my usual manner, specimens of mortar made with the refuse of soap-lees, and my best sand, in different proportions, and others made with this sand, lime, and the refuse matter, in various proportions, I found the first destitute of the most useful properties of good mortar; and the others were defective in proportion to the quantity of the refuse matter relatively to that of the lime. Whether this matter improves mortar made with gravel and the common chalk lime, or increases the defects of it, is a question not worth our notice.

"The experiments lately related show that lime is the more unfit for building and external incrustations as it contains more gypsum, and I must now remark that most kinds of limestone used in England contain considerable quantities of this matter, which is not much corrected in the burning; but as I have in the second section enabled my readers to discover this imperfection, I hope I shall be excused from the invidious office of deprecating or recommending any particular lime-stone, or manufactory of lime.

"The cautions which our last-mentioned experiments suggest in regard to the use of water are especially necessary where wells and springs abound with one or more of the above-mentioned salts, and it is not to be presumed that the quantity of these contained in water which is used for culinary purposes cannot be injurious to mortar, for I know that silenite, Epsom salt, the very deliquescent salts, com-

pound of magnesia, and marine acid, and of calcareous earth and the same acid, may, together with a little sea salt, be natively dissolved in water, to the quantity of half an ounce in a gallon, without effecting the taste of it sensibly.

"When we consider the quantity of water necessary in slaking the lime, making the mortar, and wetting the thirsty bricks, and the smallness of those portions of salts whose injurious effects were discoverable in the course of one year, or in a shorter time, we find sufficient grounds for concluding that such saline waters will be found hurtful in mortar, before many years elapse, particularly where it is exposed to moisture. Indeed this has been already experienced of sea salt, even in the small quantity of it introduced in mortar, when the sand is taken from the sea-shore.

"The easiest method of discovering the quantity of saline matter in water, consists in evaporating it slowly to dryness, and weighing the residue. Water which deposits calcareous earth as soon as it is heated ought to be cleared by subsidence or filtering, before the evaporation is completed.

"When a choice can be made, rain water is to be preferred, river water holds the next place, land water the next, spring water the last, and waters noted medicinally or otherwise for their saline contents ought not to be used at all in mortar, for the salts contained in them are those which were tried, the vitriolated tartar excepted."

Experiments showing the effects of Skimmed Milk, Serum of Ox-blood, Decoction of Linseed, Mucilage of Linseed, Olive Oil, Linseed Oil, and Resin in Mortar, and the effect of painting Calcareous Incrustations.

"At the same time and in the same mixtures of the best sand and lime, I tried skimmed milk, serum of ox-blood, decoction of linseed (strained), and thick mucilage of linseed, in the place of lime-water.

"The mortar made with any of these was fatter as the liquor was more glutinous, but was as liable to crack as mortar made with water. In the course of a year it appeared that each of these liquors encourages a vegetation to take place on the surface, which gives it an ugly appearance and tends to ruin it, and that they all prevent the cement from acquiring the experienced hardness of our best compositions, or indeed from having any competition with them in this particular.

"The notion, therefore, that is entertained by some builders concerning the use of skimmed milk and blood is erroneous, unless it be confined to the viler kinds of mortar, which may perhaps be improved by them, because a composition of sand, whiting and mucilage grows harder than that of whiting and sand kneaded with mortar.

"It seems that glutinous liquors and good lime act reciprocally on each other, in the time of mixing them, to the destruction of their respective characters, and particularly to the conversion of a part of the quick lime into whiting; and that if any kind of mortar is is improved by them, it is then especially, when the workmen takes advantage of the fatness induced by them, and using less than his customary quantity of lime, secures his work from cracking.

"*Olive oil*, mixed with good mortar or substituted in the place of a part of the lime-water, rendered the cement defective, as the quantity of oil was greater. The greatest quantity used was half that of the lime

"*Linseed oil*, used in the same manner, makes the mortar fatter, retards the drying of it, and prevents it from acquiring in any time, so great a degree of hardness as it otherwise would have. It was the more hurtful as the quantity of it was nearer to that of half the lime, in much smaller quantities it was less injurious than olive oil. From my observation on this subject, and on the compositions called oil cements, I have reason to conclude that no oil ought to be used in a

cement which consists chiefly of sand, lime and water, nor any water, or watery liquor, in a cementitious mixture, which is moistened or kneaded with oil chiefly.

"As linseed oil, whiting and sand, make a cement which hardens to a great degree in dry situations, and abides the weather a long time before the hardened oil relents, it is not improbable that linseed oil may meliorate mortar made with bad lime. But good lime and linseed oil seem to injure each other, in forming a kind of saponaceous compound, with the lime-water of the mortar.

From the experienced effects of saline, gelatinous and oleaginous matter, I infer that cow-dung, which I have not tried, would impair good mortar. It makes the common mortar fatter, and in that respect more convenient for "pargetting" the interior surface of chimney flues; it seems likewise to prevent the parget made with bad lime from drying so quickly, and from cracking so much, as it otherwise would do; the fibrous part of the dung contributing largely to this latter effect. On these grounds it may be useful in bad mortar thus applied, whether it increases the hardness of it or not, although it is likely to impair good mortar.

"*Powder of resin* intimately blended with mortar by grinding it with a part of the lime, and lime-water, was hurtful according to the quantity of it, the greatest quantity tried being one-fourth of that of the lime.

"Before I knew the event of these experiments I made an incrustation on a wall fronting the south, but shaded from the sun after mid-day, with a cement composed of seven parts of my mixed sand, one of the best stone lime, and the necessary quantity of lime-water. As soon as the incrustation was dry, which happened in four days, I painted one-third of it with linseed oil, prepared for painter's use, another third with white lead paint, and the remainder was separated from these by a channel cut between them.

"After fourteen months, the last-mentioned portion was very hard near the surface, and the induration extended very deeply into the

mass of it, though not in so great a degree of perfection as that of the surface. The painted portions were also very hard at the surface, but internally much weaker than the other.

"From my observations of these specimens, and of divers incrustations in this city, which, being made of bad calcareous cement, have been painted and sanded, in order to fill the cracks and fence them from the weather, I have had sufficient reason to conclude that an incrustation, made as good as it may be with lime and sand, and lime-water, is not better by painting it as soon as it dries; that this covering retards the induration of it, by cutting off its communication with the air; that it therefore renders it liable to be irreparably injured in wet weather whenever the water can get behind the paint; and that if paint or oil ought ever to be applied on such stucco, it ought not to be used in less than a year after the incrustation is made. I likewise found that the painting and sanding of the common incrustations, contributes very little to their duration, although it hardens them at the surface, for it does not effectually prevent them from cracking, and it avails very little to paint the cracked stucco again, because cracked stucco is always 'hollow,' as the workmen term it, that is, it parts from the wall in the parts contiguous to the cracks, sounds hollow on being struck with the knuckle, and falls off in a few years, if it be so thick and large in extent as to break the adhering portions by its weight."

Experiments showing the effect of Sulphur introduced into Mortar by different methods.

"In my first trials of sulphur, it seemed to be useful, and this led me to try it in so many different ways, and in so many mixtures of limes and sands, and of these with flint-powder and divers other substances, as would render the recital of all my observations on the effects of it, inconsistent with the plan of this essay; I must, therefore, content myself with communicating those which I think most

useful, in such terms as may give some intimation of the manner in which the experiments were made.

"When the powder of sulphur was mixed with mortar already made of good materials, and did not exceed one-thirty-second part of the mass, is seemed to improve it, in the first and second month, and sometimes during a longer time of comparison with mortar made of all the same materials (except sulphur) in the same proportions, but in ten or twelve months the sulphur was found to be injurious, and the more so as it exceeded the foregoing proportion. The most hurtful effect of it, was, its disposing the mortar to relent in long continued rains, and become quite friable after a few alternatives of freezing and thawing. It had the same effect in mortar containing several of the ingredients already named, and of those hereafter to be mentioned.

"When the sulphur was mixed with fresh powdered lime, and these were ground briskly with lime-water, a calcareous liver of sulphur was formed, proportionate to the quantity of sulphur used; and the mortar made with this mixture and sand, or with this and sand and other ingredients, was worse than mortar contaning an equal quantity of the sulphur mixed in it in the former method.

"The transparent liquor called liquid calcareous liver of sulphur, which consists of sulphur dissolved in water by the intervention of lime, being used instead of water in making mortar with sand and lime in any proportions, was found more injurious than three times the quantity of undissolved sulphur was, in the first-mentioned method of using it, and this liquor had the like effect in mixtures of mortar with divers other ingredients; whence I infer that sulphurous mineral waters ought not to be used in mortar.

"If the plan of these experiments had not comprehended the noxious as well as the useful ingredients, and I had not resolved to distrust every theory, I might have foretold the event of these mixtures, in consequence of my certain knowledge of the operation of sulphur, lime, and air on each other.

"When sulphur and lime are moistened with water, and exposed to air, the acid of sulphur being attracted by the lime, whilst the phlogiston of the sulphur is attracted by the air, a decomposition of the sulphur takes place, and new compounds are formed. The acid and lime gradually form selinite, or gypsum, whilst the air combined with the phlogiston is wafted away. Therefore, lime, by so much of it as is thus expended in forming gypsum, is not only unable to act as a durable cement of the grains of sand, but is capable, according to the experiments of the sixteenth section, of counteracting the cementing power of the residuary part of it, when the mass of sulphurated cement is exposed to the weather.

"The pleasing warm color which sulphur induces in calcareous stucco, whilst it is fresh, and the promising appearance of such incrustations in the first year, have, if I am rightly informed, already misled some to apply it freely at their own risk. I wish these observations may serve to undeceive them.

"About this time, the imitation of colored stones, by incrustations, became an object of my attention, and some of the subsequent experiments were made with a view to it, as well as to the purposes already expressed."

Experiments showing the effects of Crude Antimony, Regulus of Antimony, Lead Matt, Potter's Ore, White Lead, Arsenic, Orpiment, Martial Pyrites, and Slaked Mundic, in Mortar.

"*Crude antimony* reduced to an impalpable powder, and then ground with the lime, and lime-water, operated in mortar as sulphur does when it is used in the same manner and in the quantity which the crude antimony contains.

"The antimonial powder, moreover, induced a disagreeable bluish color, which in a little time became brown, and afterwards, yellowish. When the powder of antimony was mixed in the mortar after it was made it was less injurious.

"*Regulus of antimony*, tried in the same way, seemed to have no other effect than that which is produced by the admixture of flint powder, or other fine powders of hard bodies.

"*Powdered lead matt*, and *potter's ore of lead* acted like crude antimony but more slowly and weakly in equal quantities of them.

"*White lead* was found exceedingly injurious, which I expected, for I had long before discovered and shown in my public courses on chemistry, that a great part of white lead is acidulous gas, into which vinegar is easily convertable in the process for making white lead, and in many others; and I foresaw that the lime, attracting this matter, would be reduced to the condition of whiting in the time of making the mixture, and that the mortar would consequently be defective. The white lead, as fast as its acidulous gas is drawn from it by the lime, becomes yellow, like masticot. As white lead improves the oil cements, these experiments show that there is no true analogy between the calcareous water cements and those which are called oil cements.

"*Arsenic* operated in mortar like the neutral salts, and orpiments produced the injurious effects experienced of sulphur and of arsenic, which effects were greatest when the orpiment was ground with the unslaked lime and lime-water. Orpiment imparted a dark brown color at first, which soon became yellow and afterwards disappeared.

"The *martial pyrites*, called mundic, heated to redness, and then slaked by moistening it with water whilst it was hot, operated like crude antimony, with this difference only, that a greater quantity of it was required to produce the same effect; for this reason, as I conceive it, that the quantity of sulphur in martial pyrites is less than in crude antimony, and being held in it by a more forcible attraction, is prevented from acting as freely in the lime of the mortar. The color induced by the slaked mundic was at first bluish, and afterwards turned to that of iron rust.

"The *mundic* which was from Cornwall, used in its native state, in mortar, kept me in suspense upwards of twelve months. It was tried not

only on tiles but in large incrustations on walls, because it promised great advantages at first. When the quantity of it did not exceed one-twenty-fourth of that of the mortar, it manifestly increased the induration of the cement during the first nine months, but after fourteen or fifteen months it disposed the incrustation to relent, the more as it was oftener wetted, or as the place was damp, and from being exceedingly hard, to become penetrable to a pointed instrument, pushed only with the hand, and as brittle as chalk-stone. The color and changes of color of the mortar containing native mundic, are similar to those produced by the slaked mundic, and are not at all pleasing to the eye. The effects of much smaller quantities of this matter in mortar do not yet appear so clearly, but there is no reason to presume that they will not be of the same kind, though in a smaller degree.

"These and the preceeding experiments, indicate that all bodies soluble in water, not excepting arsenic, and all those which are capable of efflorescing, or of being decomposed by air and moisture, are hurtful in mortar; and they teach us to avoid those kinds of gravel which are impregnated with pyritous matter, whether it be arsenical, metalic, aluminous, or calcareous.

"The effects of regulus of antimony, and the speedy decay of the cheaper metals, however perfectly they are de-sulphurated, give strong grounds for presuming that calcareous cements, which are to be exposed to the weather, are more likely to be injured than improved by metallic matter introduced in any form."

Experiments showing the effects of Iron Scales, Washed Colcothar, Native Red Ochres, Yellow Ochres, Umber, Powder of Colored Fluor, Colored Mica, Smalt and other colored bodies, in Mortar. Advice concerning Colored Incrustrations, Inside Stucco, and Damp Walls.

"*Iron scales* from a smith's forge, which consist of iron semi-calcined, and are thought by many to improve mortar, were tried

eighteen months ago,(by grinding them to fine powder,)and mixing them in mortar, to half the quantity of lime, and in smaller proportions.

"The larger quantities, in the course of twelve or fourteen months, appeared to be hurtful; and by these I judge of the smallest, which do not yet appear to produce any remarkable effect in incrustations made in any situations. But in those which reached near the ground, and in others made on tiles which were laid flat on the ground in a shaded damp corner, in both of which instances the incrustations were always moist, the iron powder seemed to render the cement a little harder than it would otherwise become in the same time in such circumstances, and it certainly made it closer in the grain.

"By these experiments, I am inclined to think, that iron powder, which, during its conversion to rust, imbibes a good deal of acidulous gas and air, and swells considerably, may be used with success, where the proper induration of good mortar is prevented by continual moisture, and the chief purpose of the cement is to exclude water perfectly, by the closeness of its texture, to which the swelling of the iron contributes not a little. If it is capable of producing any desirable effects in cements otherwise circumstanced, these are to be expected only when the quantity of it does not exceed one-eighth of that of the lime, or one-fiftieth of that of the mortar.

"*Washed colcothar of iron*, native red ochres, yellow ochres, and umber, had the effects of smaller quantities of terras, or of equal quantities of flint powder.

"*Colored fluor* and micaceous stones, colored marble, smalt and divers other colored substances, which are insoluble in water, reduced to fine powder, imparted their respective tints to the incrustations, but acted like flint powder.

"From the experienced effects of colored calces of iron, and of divers sulphurated and perishable metallic powders, I learned that these ought not to be used in external incrustations, since they render them more defective, as they color them deeply; and I turned my thoughts

to the discovery of some other expedient for inducing permanent color, without injuring the cement.

"I soon found that this may be done, with regard to the lighter and pleasanter tints, by the use of colored sands, or the coarse, gritty sorted powder of hard and durable colored bodies. Lynn sand affords a white cement, which is the better as more of the finest part of the sand is sifted out. Thames sand makes a grey cement, not unlike Portland stone, and this color is agreeably varied by the use of grey bone-ash, of which we shall presently treat.

"A rich yellow tint is obtained by using the golden yellow sand, of which kind there is one near Croydon, in Surrey, and a small quantity of which mixed with Lynn sand gives a warm white, and with Thames sand, an exact resemblance of Bath stone. These are the most eligible tints for the fronts of houses.

"Until I had tried the glistening scaly talcs, I imagined that they would serve to impart all other tints, as they may be had of any color, and are as durable as they are pleasing to the eye; but they were found to weaken the adhesion of the cement to the wall, and to make it so rough and 'short' that it was almost impossible to form a smooth, compact incrustation with it, unless the lime was used in an excessive quantity, and in the course of eight or nine months, it appeared that the cements in which they were mixed in the quantity necessary to produce stone tints, were rendered spongy, and greatly weakened by them.

"*Scaly glistening mica*, strewed equally on an incrustation, previously wetted with a thin mixture of lime-water and lime, and gently compressed, to lay the scales flat, imparts the color with the fullest effects. In this way, colored mica may be used, where it is cheap, on external incrustations, if the perspective appearance of a building can be improved by different colors of any members of it, and this kind of coloring greatly excels painting, in the fickle weather of our climate, because it lasts, unfaded, as long as the micaceous crust.

"To tinge a cement sufficiently for prospect or contrast, of any color which is not found in sand, so that the incrustation shall not be impaired, and that the color shall be as durable as the cement, I found nothing more advisable than to use, in the place of the sand, or of a part of it, colored glasses or colored stones of the hardest kind, beaten to coarse powder, the finer parts of which are to be washed away, not merely because they are injurious to the cement, but because I observed that they contribute but very little to the intended color.

"The drying, induration and the texture of incrustations made on brick walls, and other irregular surfaces, are always so far unequal as to exhibit visible traces, which deform the work, and cannot be effectually obliterated by any known method so convenient as that of covering the first coarse incrustation, after it has dried, with another coat which may be finer and smoother. Thus the expense of fine grained, smooth or colored stucco is rendered moderate, because the finer, or the coloring materials may be reserved for the exterior coat, which will last for ages if the cement be good, as we shall show when we come to considerthe experienced duration of the best calcareous cements.

"As the mouldings and paintings which are expended on the soft stucco now used, and which contribute so much to the magnificence of our apartments, can be equalled in their ornamental effects by the double incrustations which I have described, and greatly exceeded by these last, in the hardness and durability of them, I do not doubt that plasterers will adopt this improved method, when they find that it is consistent with their own interest, as well as that of their employers. I am not sufficiently acquainted with their business to form a just estimate of this subject, but I will submit to their consideration a few observations which would influence me very much in the choice of stucco for a house of mine.

"The compositions heretofore used for stuccoing in-doors are capable of hardening considerably, and when they are laid on the naked walls, soon became tarnished, unsightly, and inconvenient, by

the damps which workmen call 'sweating,' and which are in my opinion of two kinds, one I will call damp by 'transpiration,' and the other damp by 'condensation.' The damp by transpiration occurs when the principle walls are stuccoed before they have dried, or when the materials of them are so spongy as to imbibe the rain, and the circulation of the air within the house is not sufficient to waft away the moisture which transudes from the wet wall into the stucco, and especially when the exhalation of this moisture from the stucco is impeded by the closeness of its texture, for all such bodies retain moisture the more forcibly as their pores are smaller and as the air meets more difficulty in pervading them. I see no reason to doubt that this inconvenience would be obviated by making the incrustation of a texture similar to that of the materials on which it is laid, and that the cement made with about seven parts of sand, one of lime, and the lime-water, and improved as we shall teach hereafter by the admixture of bone-ash, would continue dry in such circumstances, because moisture quickly exhales from it, by reason of its texture.

"The damp which seizes incrustations when the walls are badly constructed, when the joints of the facing bricks become hollow by the decay of the mortar, or when the copings or gutters are defective, do not fall under our consideration.

"The damp by 'condensation' appears most in the finest and closest incrustations, however perfect and old the walls may be. To find the proximate cause of it, we need only to advert to that which gathers on glass windows, whilst the wainscot and other spongy bodies which serve to enclose the same rooms, remain dry, or to the moisture which gathers on walls faced with the closer kinds of ornamental marble, in sumptuous buildings, at the same time when the walls and incrustations contiguous to them, and are of a coarse texture, are quite dry. In these and other instances we may perceive that the damp is owing to the closeness of these bodies, and that a stucco pervious in a certain degree to air and moisture, will be free from it, as well as from the other lately mentioned.

"The plasterers, finding their stucco which is as fine and close as they can make it, liable to contract these damps, especially on the principal walls of houses, case them with lath-work, on which the incrustation is laid, distant from the wall. In this way they obviate the appearance of damp, but they at the same time contract the rooms, and narrow passages, and stair-cases sensibly, at a great expense. This is enhanced by the repeated plastering necessary to fill the slender cracks which disfigure their incrustation during the drying, and by the oiling or painting which is finally required to hide this defect completely, if not to give color. Thus the work becomes costly, although the plasterer's profit is moderate.

"On these considerations I am inclined to the opinion that it will be found as advantageous to the plasterer as to his employer, to prefer our cement before any other, for internal incrustations, especially when no other color is required, besides those which may be imparted by colored sand, or materials which do not greatly exceed it in price. I would not interfere with the workman in forming an exact comparative estimate of the expenses, if I could do it, but I will venture to affirm that an incrustation made as I have described, or in the improved method hereafter to be shown, will be found ultimately cheaper than any other yet discovered, for the following reasons, viz.: It will be more durable by reason of its greater hardness; it will retain its color longer unfaded, because the coloring materials do not tarnish, or perish the paint; it will preserve the sharpness of the moldings, and the elegance of its appearance longer, because it will not require the frequent painting, which soon blunts the figures and moldings of ordinary stuccoes; it may be finished with less labor, because it is not apt to crack in these circumstances, and does not need many coats and repeated plastering; and, as it is not likely to contract damp, it will save all the expenses and inconveniences of lath-work, whether it be laid on partitions or on principal walls, provided the cement applied on the former be made of the finest materials.

"If a polished and white surface of our stucco should be required,

it ought to consist of two layers; the first of which is to be coarse, and capable of hardening to the highest degree, the second is to consist of flint powder, lime, and lime-water, and is to be laid on very thin, and finely smoothed. To give a rich color together with a smooth surface to our best incrustations, we must use in the place of flint powder for the finishing coat, the colored powder of sands, or stones, or glasses, and introduce as much of the coloring ingredients used in painting as will be sufficient to give the required appearance, avoiding those which are spoiled by lime.

"To my eye, the warm white, or colored stucco, which is not quite smooth, is the pleasantest, but those who prefer the smoothest, may have it made at a moderate expense, in this last-mentioned method, in which the useful and solid part of it, contributes to the support and duration of the weaker ornamental coat, which thus circumstanced is likely to preserve its beauty for a very long time, although it might in the weather be impaired in three or four years."

Experiments showing the effects of common Wood Ashes, calcined or purer Wood Ashes, Elixated Ashes, Charcoal Powder, Sea-coal Ashes, and Powdered Coke, in Mortar; and Observations on their integrant parts, and the differences between them and the powders of other bodies.

"The ashes of wood and sea-coal, are frequently mixed with mortar, or used in the place of sand, in laying tiled floors, and even in external incrustations. Some workmen say they are used in the former case to save sand, others that they serve to resist moisture, and those who seem to be the best informed affirm that they hasten the drying and induration, and prevent the cracking of mortar which is laid very thick in order to fill the depressions of walls which are to be stuccoed; and that they are used in finer incrustations with the sole view of preventing cracks.

"The ashes of the same kind of wood, differ, according to the circumstances in which they are formed, even upon the same hearth, not only in color, but in other particulars known to chemists, which I shall attend to presently. As the separation of these different sorts of ashes is not practicable at a moderate expense, and is never attempted by the workmen, I contented myself, at first, with procuring the ashes of cleft pollards, burned on the hearth, and with sifting the whole quantity of them, to free the finer parts from the fragments, and coarse powder of charred wood, which formed a great part of the bulk of them. The sifted ashes were gray, inclining to brown, strongly alkaline to the taste, and viewed through a convex lens, were found to contain a considerable quantity of fine charcoal powder, which I estimated at one-sixth or more of the bulk.

"To learn the effect of the purer ashes, or of the more dephlogisticated earthy and saline parts, separated from the charcoal, I took about a gallon of the sifted ashes, and burned them on a test in a reverberatory furnace, with a heat not exceeding that of a culinary fire, taking care to accelerate the combustion of the charcoal powder contained in them, and render it equable through the whole heap by stirring it, and presenting fresh surfaces to the air, until the whole was rendered incombustible. After this process, the powder which I shall call *calcined wood ashes*, was rather brown than gray, and retained its saline taste.

"On trying the sifted wood-ashes in my best mortar, and in other mixtures of sand and lime, I found that they gave the cement a spongy texture, and enabled it to dry without cracking, when the lime was not used in excessive quantity, but that they prevented it from acquiring the hardness of mortar made of lime and sand only; so that the advantages they promised to afford in certain circumstances appeared to be counterbalanced by the permanent weakness induced by them; which latter effect was the greater, as the quantity of the ashes came nearer to equal that of the lime.

"The calcined wood-ashes likewise prevented the mortar from

cracking, without making it so spongy, but they materially impeded the induration of it, and disposed it to be injured by rain, in the same manner as small quantities of alkali were found to do.

"On a strict comparison, the calcined wood-ashes, which we may consider as ashes freed from the charcoal powder, appeared to be much more injurious than the uncalcined. This I imputed to the greater quantity of alkali in the former, which is hurtful in a double capacity, first, as a saline body, and secondly, as a compound which yields its acidulous gas to lime, in the instant of mixture, and consequently impairs the cement.

"Mortar made with bad lime in the usual proportions may nevertheless be improved by sifted wood-ashes; for the coal and earthy parts of these, if they were only equivalent to so much sand, render it less liable to crack; and the bad effect of the alkali, may be greatly overbalanced by this advantage, in an incrustation which is required to be rather uniform and secure from cracking, than hard and durable in the highest degree.

"I must not omit this opportunity of observing that calcined wood-ashes, and even the sifted fresh wood-ashes, improve *plaster-of-paris*, in hardness, to a very great degree, if it be kept in a dry place. The solution of this phenomenon is not difficult.

"Any person who intends to repeat my experiments on calcined wood-ashes ought so take care that they be not calcined with a stronger heat than I described, for if he exceeds this, the ashes, after the signs of their combustion have ceased, will smoke strongly, a part of the saline matter being sublimed in the meantime, and the remaining earthy and saline portion will form a light gray or brown, semi-vitrified, gritty powder, or will concrete in lumps. This matter will then be found insipid, and equivalent to sand, in mortar, as I have experienced, for it differs as much from wood-ashes, as the powder of potter's stoneware differs from the raw clay.

"Whilst I was employed in these experiments the following thoughts occurred to me. The ashes used by workmen being passed

through a coarse sieve may consist for the greater part of charcoal which afterwards is beaten finer in making the mortar.

"The ashes used by builders, whose durable works authorized this practice, might have been the refuse of manufactories of potash, into which the saline matter is always carefully extracted from them; and charcoal powder, or elixated ashes may greatly improve mortar, although ashes finely sifted and replete with salts would impare it. I therefore boiled my calcined wood-ashes in water, and repeated this operation twice in fresh water, knowing that one elixation does not free the ashes perfectly from the saline matter. I then dried the insipid ashes thoroughly and used them in this state, under the name of *elixated wood-ashes.* At the same time I provided charcoal powder sifted through the same sieve which I used for the wood-ashes.

"After a great many experiments made in the usual manner with the elixated ashes, I found that they rendered the mortar spongy, disposed it to dry and harden quickly, and prevented it from cracking, more effectually than the like additional quantity of sand would do it. They did not appear to induce the defects attending saline bodies in mortar, they only made it weaker, as the quantity of the elixated ashes was greater relatively to that of the sand and lime.

"This weakness, however, was not such as the unwashed ashes or saline bodies produce, but rather of the kind which I pointed out in those parts of the foregoing sections, wherein I endeavored to show that cementitious masses resist edged instruments, or any force tending to break them, the more weakly as they contain more of the softer and brittle calcareous matter, or as softer grains are substituted for a part of the sand.

"In every comparison of the specimens containing unwashed wood-ashes, with those in which the elixated ashes were mixed in the same proportions, it clearly appeared that the latter are to be preferred, and that neither of them ought ever to exceed half the quantity of lime, in good mortar.

"As *flint powder* and other earthy powders were found to dispose

mortar to crack, I could not conceive how the elixated wood-ashes operated so effectually in preventing this defect, until I examined them attentively, and found them to differ from the other powders in two particulars. Elixated wood-ashes contain very little powder of the finer kind, they feel gritty between the fingers, and appear to consist of ragged, spongy, small grains, compressible to a considerable degree in the heap. How a powder thus conditioned prevents the cracking of mortar or otherwise improves it, I shall attempt to explain after stating other facts upon which my notions of this subject are founded.

"*Charcoal powder* had the same effects as elixated wood-ashes, with these differences only, that the cements containing the larger quantities of charcoal powder could be more easily cut, and were of a bluer color, than those containing the like quantities of elixated wood-ashes. The powder which I used when sifted like the ashes, and viewed through a microscope, answered to the description lately given of elixated ashes.

"*The screened ashes* of Newcastle coal consist chiefly of charred coal or coke, and as they contain very little saline matter, are insipid. When I reduced them to powder, and passed them through the sieve, they answered to the description given of elixated wood-ashes and produced nearly the same effects in mortar. They did not weaken it so much as charcoal powder had done, which I impute to the greater hardness of the small grains of coke.

"In all these comparisons, it is to be understood that I made them at the same periods of the induration of the several specimens.

"From these experiments, I conclude that, where a choice can be made, these powders are eligible in this order: 1. Elixated wood-ashes freed from the finest powder in washing; 2. Powdered coke or sea-coal cinders; 3. Charcoal powder; 4. Rough wood-ashes, powdered. But well-burned fine unwashed wood-ashes, ought not to be used at all in external cementitious work, or incrustation.

"The last of these gives a disagreeable gray or dusky color to the

cement; and the others a bluish or slate color, still more offensive to the eye, for which reason they are unfit for any work that is not hid from the view.

"As my reader may not fully understand what I briefly mentioned concerning the sensible difference between these last examined powders and others noticed in the preceding sections, I will thus exemplify my notions.

"Wood consists of watery and volatile parts which are expelled by heat, and of fixed parts which constitute the charcoal; and charred wood, which greedily imbibes air or water in great quantity, may be considered as an assemblage of capillary tubes of divers figures and sizes. So we may likewise consider the fragments of charcoal, each a visible grain of its powder. But as the most brittle bodies are flexible when they are made sufficiently thin, the charcoal powder is an assemblage of small flexible or compressible tubulated bodies.

"As the charcoal which is the fixed and more solid basis of wood, is spongy after the juices are expelled in charring; so the ashes of charred wood are, after the elixation, an assemblage of spongy or tubulated grains out of which the phlogistic matter has escaped during the combustion, and the texture of these grains differs from that of the grains of fine sand, or of flint powder, in the same manner, if not in the same degree, as the texture of sponge differs from that of flint. And we may conceive the unwashed wood-ashes as a heap of small spongy bodies clogged with alkaline salt.

"Upon the same grounds, the relation of coke or sea-coal cinders to the raw coal is analagous to that which charcoal bears to wood, or spongy pumice stone to porphyry; and transferring these observations to bones, and considering the smaller vessels and finer texture of them, than of wood, we shall find the powder of charred bones to consist of tubulated or spongy bodies like those of charcoal powder, but pervious by slenderer and harder tubes, and bone-ash, which is the gritty powder of well-burnt bones, to have the same

relation to the charred bones as elixated wood-ashes have to charcoal powder.

"Thus I have thought of these substances after having observed what happens to them in the preparation; examined them by a microscope, experienced their effect to be so different from those of finest sand, or powdered stones in mortar, and finally discovered by repeated experiments, the detail of which is not now necessary, that semi-vitrification, which destroys the spongy texture, and levigation which breaks these spongy grains down to the particles of which they are constructed, render charcoal powder, wood-ashes, powdered sea-coal cinders and others of the like kind, incapable of acting in the manner described in calcareous cements.

"All these things being considered, I impute the effects of these ashes, or powders, to the tubulated structure and compressibility of the integrant parts of them, and in the next section I shall offer all that I have attempted further, theoretically or practically, relative to this subject."

Experiments showing the effects of White and Gray Bone-Ashes, and the Powder of Charred Bones, and Theory of the Agency of these in the best Calcareous Cements.

"Long before I had tried all the powders heretobefore mentioned, I used bone-ashes in many experiments, and saw the effects in mortar. For the sake of brevity and perspicuity, I reserved the relation of them for this section: and in order to show more clearly the analogy in texture between bone-ashes and the powders lately men tioned, and to suggest the means of procuring them in any part of this country, I will premise a sketch of the most profitable processes by which they are prepared, at a moderate price not exceeding that of good lime.

"The bones collected in great cities are broken to small fragments in a mill, and boiled in water, in order to extract and save the oil of

them. They are then put into a large iron 'still,' through an aperture which is stopped up closely after the charge is made, The still, which opens into an apparatus of refrigeratory vessels, is heated gradually to redness, until all the volatile alkali, commonly called spirit, and salt of hartshorn, is expelled from them, together with the empyreumatic oil, water, and certain elastic invisible fluids. The alkali being the only valuable article amongst these, is retained and condensed in the refrigeratory tubes and vessels, with all possible care, whilst the lactic fluids, lest they should burst the vessels, are suffered to escape in places distant from the fire, or the flame of candles, because they are combustible, and if they catch fire whilst air remains in the condensing vessels, explode like gunpowder.

"The bones thus heated, without being exposed to the air, are charred to blackness, but still remain combustible. When they are required in this state, the iron still is kept closed until they are cool, and then the blackest of them are ground to fine powder, which is used as a substitute for ivory black, which is prepared in the same way from ivory. The coarser powder of these is what I understand by powder of charred bones. But when this is not the manufacturer's design, the door of the iron still is left open whilst it is hot, and the charred bones which flame and burn when they meet the air are thrown into a kind of kiln, at the bottom of which the air can freely enter, and maintain the combustion until the bones are burned to whiteness for the greater part. The white fragments are picked, and rather bruised than ground to a gritty powder by a millstone, which rolls over them vertically on an inclined circular plane. This powder, passed through a sieve, is called *bone-ashes,* which are much used in metallurgy, and fitter for our purposes in incrustations than the powder of burned bones, ground as pigments are. The fragments which have not been thoroughly burned in the kiln form a dark grey powder, and the mixtures of white and grey burned bones afford bone ashes of the lighter grey colors.

"The whole quantity of bone-ashes, which is to be used in the same

incrustation, ought to be well-mixed, for it is impossible to sort the well burnt or the gray bones so accurately as to secure an unity of color in the parcels of powder which are successively prepared, and a very small variation in the color will be apparent in the incrustation.

"Knowing that bone-ashes consist chiefly of calcareous earth, and may be reduced to lime by dissolving them in acids, precipitating the solution by alkalies, washing the precipitate perfectly, and then burning it. I tried them with sand in different ways, in order to learn how far they resemble lime in their cementing properties, and found that the sorted bone-ashes had very little effect, but that the compositions made with the levigated powder of these, and sand and water, were nearly equal in hardness to those made with whiting and sand, kneaded with water, in the same proportion, and were not so liable to crack. Hence I inferred that bone-ashes, of which five-sixths are calcareous earth, could not improve mortar by any augmentation of the cementing powers of the lime, although they might be useful in other respects, and that they could not supply the defect of lime, in quantity or quality.

"In the course of two years I made so many experiments with bone-ashes, mixed in mortar composed of lime, sand and lime-water, in different proportions, and of these with divers other ingredients, that I may venture to say, I attained a thorough knowledge of their effects, and need not hesitate to relate them in the style of precept.

"The sorted bone-ashes, mixed with mortar, in any quantity not exceeding that of the lime, dispose the cement to set speedily, without cracking, and effectually secure it from cracking, if it does not contain lime in superfluous quantity. They likewise give a texture which is the more spongy as the quantity of bone-ashes is greater, and they accelerate the induration of it, through the whole mass.

"The sorted bone-ashes increase the plasticity of fresh mortar which is made with the smaller quantities of lime, in order to secure the work from fissures, and thus they are useful in a triple view, in external incrustations, by facilitating the operation of plastering, by

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preventing cracks, and by bringing the incrustations quickly to a state in which it is not easily injured by rain.

"When the sorted bone-ashes exceed the lime in quantity, they sensibly injure the cement by rendering it weaker. How these ashes, which are not equivalent to sand in the hardness of their grains, nor to lime in their cementing powers, operate to weaken the cement may be easily conceived, in consequence of the observations made in the ninth, twelfth, and thirteenth sections. And when they are mixed in mortar, in the quantity of one-fourth of the lime, they improve the plasticity, if the mortar be 'short,' and they produce the desirable effects above-mentioned in a sensible degree, without weakening the cement in the same proportion. As a smaller quantity of them seem to be useless, and a greater quantity than that of the limes, injurious, the following rules are to be observed:—

"When it is required more to secure an incrustation from the effects of hot weather, to finish it quickly, to hide the traces of brick-work, which are apt to appear through it, and to guard it against rain, than to make it hard and durable in the highest degree, as much sorted bone-ashes must be used as lime. When the season, exposure, and other circumstances permit to attend solely to the true excellence and duration of the work, there must be used in our best calcareous cement only one part of the sorted bone-ashes for every four parts of lime. By these rules the operator may choose intermediate quantities adapted to his purposes.

"The coarser bone-ashes used in making cupels, and tests, do not go so far (so the workmen express themselves) or do not operate so effectually as the sorted ashes in equal quantities of them, by weight; and finer or levigated bone-ashes are rather injurious than useful in the coarser cements.

"The black powder, of charred bones, and gray bone-ashes have nearly the same effects as sorted bone-ashes have, when the powder of them is sorted in the same manner, excepting what relates to color.

"These observations on bone-ashes were made on specimens of mortar laid on tiles, and small pieces of incrustations made on the walls of my house, and on the fence-walls hehind it. But they were not confirmed thoroughly, until a comparison was made between large incrustations laid in trying aspects, and containing bone-ashes, with those close by them, of my best mortar, some months afterwards, when I discovered the difficulty (expressed in the fourteenth section) of making extensive incrustations, in certain circumstances so free from defects as the smaller ones were, which I had made at home.

"By the analogy of bone-ashes to cinders, or ashes of other bodies by the effects of them in my experiments, and by the observations I have made on houses and garden walls which have been fronted or entirely stuccoed with my cement, I have been led into the following opinions, concerning the agency of bone-ashes in calcareous cements:—

"The mortar which contains bone-ashes, partakes in some degree of the elasticity and sponginess of their grains, and is the less liable to crack in setting, for the same reason that sponginess is, in any other body, and effectual preventive of fissures in drying, or because any contraction of the lime-paste, in consequence of the exhalation of its water, is combined to the circuit of the spongy grains compressed in beating, trowelling, and floating the cement, and is thereby prevented from running longitudinally to form fissures. The same texture of bone-ashes, contributes to this effect, or causes it, upon other principles, which are less exceptionable, and there is no reason to doubt that bone-ashes, whose grains are tubulated in all possible directions, which greedily imbibe water, and emit air, and which render the mortar in which they are mixed, manifestly bibulous; facilitate the entry of acidulous gas into the cement, and that this matter entering, so fast as the water exhales, occupies the place of the water in the cement, and by preventing the contraction of it, avoids fissures. The speedy induration of the cement which implies a quick

and copious accession of acidulous gas, according to our opinion and experience, is a proof of this agency of bone-ashes, as well as an effect deducible from their texture, and from these premises, we may easily conceive how they accelerate the setting of calcareous incrustations, and tend to secure them from the injuries of variable weather.

"These properties of bone-ashes render them peculiarly useful in incrustations made within doors, on principal walls, and the admixture of them in half the quantity of the lime, or in a greater quantity, is the improvement I pointed out in the twentieth section, whereby the damp that disfigures the common incrustations made in the circumstances there described, may be obviated without incurring the expenses of lath-work.

"Those who know that one-sixth part of charred bones, or about one-tenth part of well-burned bones, is phosphoric acid, may have some doubt concerning the duration of a cement in which they are mixed in large quantity, unless they consider that the strength of the cement does not depend on them, and that it is impossible for the phosphoric acid to quit the lime of bone-ashes, in order to dissolve the saturated lime of the cement. Though the bone-ashes should perish in a century, which is not probable, the cement is not likely to fail on this account, provided the quantity of them is not excessive.

"Thus I surmounted the difficulties mentioned in the fourteenth section, and made my best calcareous cement applicable in all cementitious and crustaceous works, external or internal, without inducing in it any disagreeable color or other imperfection.

SPECIFICATION OF THE AUTHOR'S PATENT CEMENT.

"To all to whom these presents shall come, &c.,

"Now know ye, that in compliance with the said proviso, I, the said Brindley Higgins, do hereby declare that my invention of a water cement or stucco, for building, repairing and plastering walls, and for other purposes, is described in the manner following (that is to say): Drift or quarry sand, which consists chiefly of hard quartoze, flat-faced grains with sharp angles; which is the freest, or may be most easily freed by washing, from clay, salts, and calcareous, gypseous, or other grains less hard and durable that quartz; which contains the smallest quantity of pyrites or heavy metallic matter, inseparable by washing, and which suffers the smallest diminution of its bulk in washing in the following manner, is to be preferred before any other. And where a coarse and a fine sand of this kind, and corresponding in the size of their grains with the coarse and the fine sand hereafter described, cannot be easily procured, let such sand of the foregoing quality be chosen, as may be sorted and cleansed in the following manner.

"Let the sand be sifted in streaming clear water, through a sieve which shall give passage to all such grains as do not exceed one-sixteenth of an inch in diameter, and let the stream of water and the sifting be regulated so that all the sand which is much finer than the Lynn sand commonly used in the London glass-houses, together with clay and every other matter specifically lighter than sand, may be washed away with the stream, whilst the purer and coarser kind of sand which passes through the sieve subsides in a convenient receptacle, and whilst the coarse rubbish and rubble remain in the sieve to be rejected.

"Let the sand which thus subsides in the receptacle be washed in

clear streaming water, through a finer sieve, so as to be further cleansed and sorted into two parcels: a coarser, which will remain in the sieve, which is to give passage to such grains of sand only as are less than one-thirtieth of an inch in diameter, and which is to be saved apart under the name of coarse sand; and a finer, which will pass through the sieve and subside in the water, and which is to be saved apart under the name of fine sand.

"Let the coarse and the fine sand be dried separately, either in the sun, or on a clean iron plate, set on a convenient furnace, in the manner of a sand-heat.

"Let lime be chosen, which is stone-lime, which heats the most in slaking, and slakes the quickest when duly watered; which is the freshest made, and closest kept, which dissolves in distilled vinegar with the least effervescence, and leaves the smallest residue insoluble, and in this residue, the smallest quantity of clay, gypsum or martial matter.

"Let the lime chosen according to these important rules be put in a brass wired sieve, to the quantity of fourteen pounds. Let the sieve be finer than any of the foregoing, the finer, the better it will be. Let the lime be slaked by plunging it in a butt filled with soft water, and raising it out quickly, and suffering it to heat and fume, and by repeating this plunging and raising alternately, and agitating the lime until it be made to pass through the sieve into the water, and let the part of the lime which does not easily pass through the sieve be rejected, and let fresh portions of the lime be used, until as many ounces of lime have passed through the seive as there are quarts of water in the butt.

"Let the water thus impregnated stand in the butt closely covered, until it becomes clear; and through wooden cocks, placed at different heights in the butt, let the clear liquor be drawn off, as fast and as low as the lime subsides, for use. The freer the water is from saline matter, the better will be the lime-water or cementing liquor.

"Let fifty-six pounds of the aforesaid chosen lime be slaked by

gradually sprinkling on it, and especially on the unslaked pieces, the lime-water, in a close, clean place. Let the slaked part be immediately sifted through the last mentioned fine brass wired sieve. Let the lime which passes be used instantly, or kept in air-tight vessels, and let the part of the lime which does not pass the sieve be rejected. This finer,richer part of the lime, which passes through the sieve, I call *purified lime.*

"Let bone-ashes be prepared in the usual manner, by grinding the whitest burnt bones, but let it be sifted so that it be much finer than the bone-ashes commonly sold for making cupels.

"The most eligible materials for making my cement being thus prepared: take fifty-six pounds of the coarse sand and forty-two pounds of the fine sand: mix them on a large plank of hard wood, placed horizontally, then spread the sand so that it may stand to the height of six inches, with a flat surface on the plank; wet it with the lime-water, and let any superfluous quantity thereof, which the sand in the condition described cannot retain, flow away off the plank. To the wetted sand add fourteen pounds of the purified lime, in several successive portions, mixing and beating them up together in the meantime with the instruments generally used in making fine mortar; then add fourteen pounds of the bone-ashes in successive portions, mixing and beating all together. The quicker and the more perfectly these materials are compounded, and the sooner the cement thus formed is used, the better it will be.

"This I call the 'water cement,' coarse grained, which is to be applied in building, painting, plastering, stuccoing, and other work, as mortar and stucco now are, with this difference chiefly, that as this cement is 'shorter' than mortar or common stucco, and dries sooner, it ought to be worked expeditiously in all cases, and in stuccoing it ought to be laid on by sliding the trowel upwards on it; that the materials used along with this cement in building, or the ground on which it is to be laid in stuccoing, ought to be well wetted with the lime-water at the instant of laying on the cement, and that the lime-water is to be used

when it is necessary to moisten the cement, or when a liquid is required to facilitate the floating of the cement.

"When such cement is required to be of a finer texture; take ninety-eight pounds of the fine sand, wet it with the lime-water, and mix it with the purified lime and the bone-ashes, in the quantities and in the manner above described, with this difference only, that fifteen pounds of lime or thereabouts, are to be used, if the greater part of the sand be as fine as the Lynn sand.

"This I call the 'water cement,' fine grained. It is to be used in giving the last coating or the finish to any work intended to imitate the finer grained stones or stucco. But it may be applied to all the uses of the coarser grained water cement, and in the same manner.

"When for any of the foregoing purposes of painting, building, &c., such a cement is required much cheaper, and coarser grained, then, much coarser, clean sand, or well washed fine rubble is to be provided. Of this coarser sand or rubble take fifty-six pounds; of the foregoing coarse sand, twenty-eight pounds; and of the fine sand, fourteen pounds; and after mixing these and wetting them with the lime-water, in the foregoing manner, add fourteen pounds or somewhat less of the bone-ashes, mixing them together in the manner described.

"When the cement is required to be white, then white sand, white lime and the whitest bone-ashes are to be chosen. Gray sand and gray bone-ashes formed of half-burnt bones, are to be selected to make the cements gray, and any other color of the cement is obtained, either by choosing colored sand or by the admixture of the necessary quantity of colored talc, in powder, or of colored vitreous or metallic powders, or other durable coloring ingredients commonly used in paint.

"To the end that such a water cement as I have described may be made as useful as possible in all circumstances, and that no person may imagine that my claim and right under these 'Letters Patent' may be eluded by divers variations which may be made in the foregoing process, without producing any notable defect in the cement, and to

the end that the principles of this art, as well as the art itself of making my cement, may be gathered from the specification, and perpetuated to the public, I shall add the following observations:—

"This, my water cement, whether coarse or fine grained, is applicable in forming artificial stone, by making alternate layers of the cement and the flint, hard stone or brick, in molds of the figure of the intended stone, and by exposing the masses so formed to the open air to harden.

"When such cement is required for water fences, two-thirds of the prescribed quantity of bone-ashes are to be omitted; and in place thereof, an equal measure of powdered terras is to be used, and if the sand employed be not of the coarsest sort, more terras must be added, so that it shall be (by weight) one-sixth part of the weight of the sand. When such a cement is required of the finest grain, or in a fluid form, so that it may be applied with a brush, flint powder, or the powder of any quartoze or hard earthy substance may be used in the place of sand, but in a quantity smaller, as the flint or other powder is finer, so that the flint powder, or other such powder shall not be more than six times the weight of the lime, nor less than four times its weight. The greater the quantity of lime, within these limits, the more will the cement be liable to crack by quick drying, and *vice versa.*

"Where such sand as I prefer cannot be conveniently procured, or where sand cannot be conveniently washed and sorted, that sand which most resembles the mixture of coarse and fine sand above prescribed, may be used as I have directed, provided due attention is paid to the quantity of lime, which is to be the greater, as the sand is the finer, and *vice versa.*

"Where the sand cannot be easily procured, any durable stony body, or baked earth, grossly powdered, and sorted nearly to the sizes above prescribed for sand, may be used in the place of sand, measure for measure, but not weight for weight, unless such gross powder be as heavy, specifically, as sand.

"Sand may be cleansed from every softer, lighter, and less durable matter, and from that of the sand which is too fine, by various methods preferable in certain circumstances to that which I have described.

"Water may be found naturally free from fixable gas, silenite, or clay; such water may without any notable inconvenience be used in the place of the lime-water; and water approaching this state will not require so much lime as I have ordered, to make the cementing liquor or lime-water, and which, sufficiently useful may be made by various methods of mixing lime and water in the described proportions, or nearly so.

"When stone-lime cannot be procured, chalk, or shell-lime which best resembles stone-lime in the characters before described, may be substituted, except that fourteen pounds and a half of chalk-lime will be required in place of fourteen pounds of stone-lime.

"The proportion of lime which I have prescribed above may be increased without inconvenience, when the cement or stucco is to be applied where it is not liable to dry quickly; and in the contrary circumstances, this proportion may be diminished, and the defect of lime in quantity or quality may be advantageously supplied by causing a considerable quantity of lime-water to soak into the work, in successive portions and at distant intervals of time, so that the calcareous matter thereof, and the matter attracted from the open air, may fill and strengthen the work.

"The powder of almost every well-dried or burnt animal substance may be used instead of bone-ash, and several earthy powders, especially the micaceous and the metallic, and elixated ashes of divers vegetables, whose earth will not burn to lime, and the ashes of mineral fuel, which are of the calcareous kind, but will not burn to lime, will answer the ends of bone-ash in some degree.

"The quantity of bone-ash described may be lessened without injuring the cement in those circumstances especially, which admit the quantity of lime to be lessened, and in those wherein the cement is not

liable to dry quickly. And the art of remedying the defects of lime may, be advantageously practiced to supply the deficiency of bone-ash especially in building and in making artificial stone with this cement.

"N. B.—For inside work, the admixture of hair with this cement is useful.

"The excellency of my cement depends, first, on the figure, size, and purity of the sand; secondly, on the purity of the lime, obtained in the choice of lime-stone, and in the perfect burning, and security in preserving it from the air, in my method of slaking, and in the separation of heterogeneous parts; thirdly, on the use of strong and pure lime-water, in the place of common water; fourthly, on the proportions of sands, lime-water and lime; fifthly, on the manner of mixing them; sixthly, on the knowledge of ingredients and circumstances which are injurious or useful; seventhly, on the use of bone-ashes of determinate size; eighthly, on the art of suiting some of these to the several purposes; and finally, on so many other particulars as render it very difficult to give a more candid specification in the usual compass, than this which I have enrolled, or to guard otherwise against evasions, than by anticipating them.

"In witness whereof, I, the said B. H.," &c.

In allusion to the foregoing specification, the author (or patentee) makes the following remarks:—

"As the specification of these letters-patent comprehends the most useful practical instructions deduced from the foregoing experiments and observations, and may serve as a concise *recapitulation*, I subjoin a transcript of it."

Experimental Comparison of Chalk-lime with Stone-lime. Advice to Manufacturers of Chalk-lime concerning the Art of making it equal, if not superior, to Stone-lime, for the purposes of Builders, Soap-boilers, and Sugar-bakers.

"All the authors whom I have consulted, who have treated of cementitious buildings and of lime, from the time of Vitruvius, who wrote on these subjects in the reign of the Roman emperor, Titus, or before it, down to the present hour, and all the artists with whom I have conversed, agree in the opinion that lime prepared from the closest lime-stone makes a stronger cement than that which is made of spongy lime-stone, and that the lime of chalk particularly is incapable of acting as effectually as the best lime-stone, in cementitious works or incrustations, which are exposed to the weather.

"This universal and undisputed notion had great influence with me in the course of my experiments, until I had discovered not only the fallacy of it, but the grounds which gave rise to it; both which I shall now expose, in the pleasing hope of rendering great service to many of my friends, and all who are proprietors of chalk-pits, or are obliged to use chalk-lime in their buildings.

"The experiments already mentioned afforded me a great many opportunities of comparing cements made of lime and sand, or with those and other ingredients in various proportions, and differing only in the kind of lime. In these comparisons I could not perceive that chalk-lime, judiciously prepared and used, was in any respect inferior to the best stone-lime; but I did not content myself with these. I made a great number of cements, with the sole view of collecting the respective merits of these kinds of lime, in small and great incrustations, in masses made to resemble cut stone, in all exposures and seasons of the year; and after the strictest comparisons of those which contained lime in equal quantities, and were treated alike in all respects, I was thoroughly convinced that my chalk-lime was as good

for any purpose of this kind as the best stone-lime in the kingdom; for I used the well-burned lime of Plymouth stone, which I reckon among the most excellent of our lime-stones.

"This stone loses seven-sixteenths of its weight in conversion into lime, and becomes as white as chalk. Chalk loses a little more in the perfect burning. Plymouth lime leaves a small gypseous residue in the solution, described in the tenth page, which is preferable to that directed in the specification; chalk lime leaves none. Therefore, the chalk lime, chemically or technically tried, appears to be equal if not superior to stone-lime, in its cementing powers, when it is properly used.

"The prejudices entertained against chalk-lime may be traced to three sources. The first is that which is mentioned in the fourth section. The vulgar criterion of the due preparation of lime consists in the slaking; and as chalk which has undergone a slight calcination and thereby lost only a part of its acidulous gas, is capable of slaking, by reason of its sponginess, the manufacturers of chalk-lime content themselves with the degree of calcination which renders it tracticable or vendible, and thus bring it into disrepute.

"The second source is mentioned in the fifth section. Chalk-lime imbibes acidulous gas, during its exposure to the air, much faster than stone-lime, and is consequently more impaired or worse, at the time of using it in mortar, than stone-lime kept in the same circumstances. As the lime may be greatly injured in this way, without slaking sensibly, and as there was no suspicion or measure of such injury, beyond what the slaking afforded, the acquired imperfection of chalk-lime was considered as the very nature of it. In our foregoing remarks, it appears that a pound of chalk-lime, placed in the quiescent air of a chamber, imbibes two ounces and a half of acidulous gas in two days; which is the shortest time in which lime is usually exposed, if we count from the moment of its being red-hot to that of its being mixed in mortar, during which interval it is in the state of absorption.

"The third source I have discovered in the structure of the lime-kilns. The cavity of a lime-kiln has the figure of a truncated cone, inverted. When the charge, consisting of lime-stone and fuel, alternately stratified, has burned for some time, the fuel is exhausted at the lower narrow extremity of the cavity, the lime in this part cools, and serves as a grate to the fuel and lime-stone above it, which continue to burn briskly, for eighteen hours longer, after the lime beneath begins to cool. During this time, the last-mentioned part of the lime is exposed to a strong current of air, and the whole charge of lime stands in the like current of air until the lime is cooled, or withdrawn; which in common practice is seldom or never done till the sixtieth or seventieth hour after the combustion of the fuel commenced.

"The injury which lime-stone sustains in these circumstances, which I have often imitated in my laboratory, is not great, because this lime is much more compact than the chalk-lime. But when we observe that the best pieces of chalk-lime of the common kilns, and those which, after beating them sufficiently, I had left in the fire-place, exposed as they are in the usual process, are always effervescent; that good chalk-lime, in a weaker current of air, imbibes more than three ounces of acidulous gas into each pound of it, in two days, according to our former experiment, and that my chalk-lime, which I remove from the fire-place as soon as it is sufficiently burned, is perfectly non-effervescent; we find that the long experienced imperfections of fresh chalk-lime are owing more to the faulty construction of the kilns, and the ignorance of the manufacturer, than to any incapacity of chalk to yield excellent lime.

"The means of preparing chalk-lime to equal stone-lime, and of making the best stone-lime, may be gathered from what I have said, and the following intimations:—

"The kilns are to be made broader and shallower in the cavity which receives the charge; the circular wall enclosing this cavity, is to be continued tapering upwards, until it terminates in a lofty flue,

in order to accelerate the combustion, and increase the heat by a quick current of air, to be regulated by opening or closing the doorway, which is to be left in the circular wall, at a convenient height for the introduction of the charge. The massive walls of the lower cone are to be lined with fire-brick, or a pyrous stone set in the best fire-loam, and are to be girded with iron. The fuel is to be stratified with the lime-stone, or chalk, and the combustion is to be so conducted, that every part of the charge shall be sufficiently ventilated and heated, and that the lowest shall remain red-hot, until the whole is well-burned. Then the current of air through the kiln is to be stopped by closing the apertures at the bottom, or the red-hot lime is to be removed out of it, to cool in quiescent air, until it is fit to be enclosed in air-tight vessels.

"A cask of chalk-lime is not to be opened until the moment when the workman is ready to slake the lime; and the greatest expedition is to be used in the slaking, in making the mortar, and in applying it to use. By this treatment, the chalk-lime will answer every end of the best stone-lime, and stone-lime may be prepared and preserved in the highest perfection which the nature of the lime-stone can admit.

"The manufacturer of chalk-lime who adopts this plan will profit by it, for good lime is not only better, but goes further in building, than bad lime; good chalk-lime will answer the purposes of the soap-boiler, in half the quantity which they use of common chalk-lime, the greater part of which serves only to waste their lees, and clog their vats; and the sugar-bakers will not hesitate about the price of good chalk-lime, when they find that it is totally soluble in pure water, and introduces no selenitic matter into the sugar. The exportation of lime to the West India islands will be a further incitement towards the improvements which I have suggested, when they understand the principles by which *lime, duly administered facilitates, but injudiciously used, impedes the granulation* of the saccharine parts of their cane juices."

POZZOLANA OR PUZZOLANA.

"This mineral being a very essential ingredient in the composition of *hydraulic cement*, a brief account of it here, may not be considered out of place, or uninteresting.

"*Pozzolana* is a greyish kind of earth, much used in Italy and elsewhere, for building under water—the best variety of which is found about Pozzuola, (Puteoli,) Cumæ, Baiæ, &c., in the kingdom of Naples; and from the former of which places it derives its name.

"The mineral, of itself, is a pale greyish powder, composed of particles so very minute, as to escape distinction even by the aid of powerful glasses, and when viewed through a microscope appear only a loose, fine irregular powder, and containing small quantities of talc spangles, and when mixed with water in a glass vessel, and well-shaken up, leaves a white muddiness in it, which requires a long time to subside; and when wetted with sea-water, immediately dries into a firm, compact mass, similar to stone, hence its value for marine works; it will do the same when mixed with fresh water, but not in so great a degree.

"Mixed with lime, *Pozzolana* makes the best possible mortar, it hardens and petrifies in water.

"The ancients were well acquainted with this substance, and its properties, and employed it extensively in the construction of moles, piers, &c. of bridges and all works exposed to direct contact with sea-water, or subject to saline atmosphere or impregnation. Vitruvius, Pliny, De Lorme, &c., set great value on it, and the latter is reported to have used it largely in France. Some have considered it to be of an aluminous and sulphurous nature.

"It is said to have been first noticed on the sea-shore of its native place, where having drifted down from the hills by the force or action of the wind, aided by the law of gravitation, or by the mountain torrents, it lodged on the beach or sea-side, and becoming mixed with

the sea-water, dissolved, and speedily acquired extreme induration and solidity, so much so as to be by many mistaken for masses of native stone.

"The remarkable property which it possesses of coalescing so quickly with water, is probably owing to its having in its composition a large proportion of a certain earth very common on the sides of hills throughout Italy, and known to the ancients by the name of *gypsum tymphiacum*, and by the moderns as *calx nativa*, and which possesses the quality of forming a kind of plaster, without being burnt.

"Puzzolana is also found in other parts of Italy than those before enumerated, as Viterbo, Bologna, &c., and frequently in the vicinity of burning mountains, from which it has been ejected in the form of ashes—in the crater or belly of which volcanoes it had been previously burnt or calcined; and which fact will reasonably and satisfactorily account for its highly cementitious properties (in its native state) without further preparation. It is said to exist in large quantities, sometimes covering the face of the country, and even whole districts to a considerable depth; and it is sometimes found in small detached pieces of an earthy and porous texture; classed by mineralogists under the genus "lava," and is considered a volcanic product.

"It is magnetic, and readily melts stone into a dark slag; it quickly hardens when mixed with one-third of its own weight of lime and water, forming a cement more durable under water than any other yet known.

"Upon analysis it has been found to contain the following components, viz.,(out of one hundred parts,)from fifty-five to sixty of siliceous earth, twenty of argillaceous, five or six of calcareous, and from fifteen to twenty of iron. This last constituent is thought to be the principal cause of its peculiar property of hardening under water. The iron decomposes the water, thus producing in a short time a new compound.

"Another examination of a specimen of puzzolana gave the follow

ing results: 44·5 of silica, 15·0 alumina, 8·8 lime, 4·7 magnesia 1·4 potash, 4·1 soda, 12 oxide of iron and bitumen, and 9·2 water in 100 parts.

"The Greeks were not acquainted with this substance, and the Romans had in this respect a great advantage over them, on account of the solidity it imparted to their buildings. When used for structures in or under water, the Romans mixed (according to Vitruvius) two parts of Pozzolana to one of mortar. The ruins of edifices near Baiæ attest the solidity of this cement.

"Puzzolana was called by the Romans '*terra puteolana*' from the place where it was chiefly obtained, and was employed by them with great advantage in the construction of their public ways at Rome, and its vicinity.

"Artificial puzzolana is made by reducing to a red heat, three parts of clay to one of slaked lime by measure.

"A species of puzzolana has been found in England and France, but it is not equal in quality to the Italian.

Puzzolanas are either natural or artificial, the former are found in situations which have been acted upon by subterraneous heat, such as is contained in volcanos, &c. They all consist of silex, alumina, oxide of iron, and a little lime; the proportions of which greatly vary in different specimens, the silex or clay, in all cases, predominating, while the lime and iron are sometimes, though rarely, wanting.

"The scoria of forges and furnaces, broken pottery, and pulverized brick or tile, are artificial substances analogous to puzzolanas. One class of puzzolanas, containing a large portion of clay or argil, resist the action of sulphuric acid; another class, with a less proportion of clay, readily dissolve with this acid, abandon the clay, which immediately separates and subsides.

"Since the quality of natural hydraulic lime depends on the mixture of various ingredients, with only a certain proportionate quantity of clay, combined with heat, it is natural to suppose that an artificial mixture of the like materials submitted to heat, would produce a

compound of equal efficacy. Experience has abundantly confirmed this opinion, and it is now known that an artificial hydraulic lime may be prepared in almost any place, at a moderate price, and equal to the natural.

"An artificial puzzolana is made by heating of slaked lime, one part to three of clay, and keeping them at a red heat for several hours; after which cover the top of the kiln with sand or earth, and when cool, pack it up close in casks for use.

"It is well known that puzzolana in itself has no cementing properties, having been found upon analysis to consist of the same component parts as the colored clays of nature, that is, chiefly of silica and alumina, with a small portion of the metallic oxides, and sometimes with a little lime; but when mixed with the weaker hydraulic limes, or even with common lime, it constitutes a hydraulic mortar, that sets under water, but more slowly than either the natural or artificial water-cements.

"John Smeaton, C. E., who erected the Eddystone lighthouse in the English Channel, is accredited as having been the first to bring puzzolana into public notice in England, and used it extensively, both in a pure state and also mixed with Watchet or Aberthaw lime, and other hydraulic ingredients in the construction of that far-famed structure, and also made several experiments upon its peculiar properties.

"Mr. Stevenson, C. E., also employed puzzolana, with a mixture of Aberthaw lime and sand, at the building of the Bell Rock lighthouse, opposite to the mouth of the river Tay (Scotland); his proportions were one measure of slaked lime-powder, one measure of puzzolana, one measure of sand.

"The most ancient sort of artificial puzzolana is composed of brick-dust or tile-dust, or fragments of broken pottery ground to powder, and being mixed with lime, produced a cement more impervious to water than common mortar made of lime and sand, and which in all probability was in common use in the time of the Romans, as may be inferred from some passages of Vitruvius. Puzzolana and brick-dust not only

resemble each other in appearance, but chemistry prove that they contain the same component parts, both being originally clays, and both being moderately calcined or burned, the one by volcanic agency, and the other in a kiln or clamp.

"This primitive sort of artificial puzzolana has been in constant use from time immemorial in the south of Europe, and especially in France, where the term 'cement' has been applied to it, which, whenever it occurs in any French work on practical architecture, may be taken invariably and exclusively to signify brick or tile-dust mixed with lime for the purpose of forming a hydraulic mortar, but which term has been supplanted by M. Vicat, who employs the phrase 'artificial puzzolana,' which is now almost universally adopted by modern authors.

"The Dutch, to whom hydraulic mortars have long been known, and of great importance, accustom themselves to burn a clay found under the sea of their coast, for the purpose of forming an artificial puzzolana, which is said to be a close and good imitation of the natural 'trass' of Andernach on the Rhine, and which is often sold and exported as such.

"A series of experiments undertaken by Col. Pasley (at Chatham) on artificial puzzolana, produced the following results:—

"1st. That the calcined blue clay of the river Medway forms better artificial puzzolana than the calcined brown pit clay of Upnor, but in its water-setting properties it is rather inferior to natural puzzolanas.

"2d. That the finest clays make the best, and pounded bricks the worst, artificial puzzolana.

"3d. That no hydraulic mortar, except cement, will set on the outside of walls, exposed to the violent action of the water.

"4th. That puzzolana mortars, as well as those of the strongest hydraulic limes, require to be protected by cement in all the external joints.

"5th. That the mortar of walls built with weak hydraulic limes

will not set under water, unless improved by puzzolana as well as being guarded all round with cement

ANALYSIS OF TRASS AND PUZZOLANA.

"The chemical component parts of Trass and Puzzolana are so nearly alike, that the one cannot possess any property not belonging to the other, though it may be in a lesser or greater degree, but it ought to be understood, that the puzzolanas and trasses even of the same locality, may somewhat differ from each other in the proportions of their component parts, and those from different localities still more, and the same remark will apply to hydraulic limes and water cements. The trass used by Mr. Stevenson on commencing the Bell-rock lighthouse, for want of puzzolana, is stated to have contained in 100 parts, silica 57, alumina 28, lime 6·5, and oxide of iron 8·5.

"The puzzolana used by him for the same lighthouse contained, silica 55 parts, alumina 20, lime 5, and oxide of iron 20.

"The following shows the component parts of the trass and puzzolana used by General Treussart at Strasburgh, as analyzed by M. Berthier:—

	TRASS.	PUZZOLANA.
Silica,	570	445
Alumina,	120	150
Lime,	26	88
Magnesia,	10	47
Oxide of Iron,	50	120
Potassa,	70	14
Soda,	10	40
Water,	96	92
	952	996

NOTES FROM THE LATE GENERAL SIR C. W. PASLEY'S (K.C.B., R.E.) WORK ON LIMES.

Pure limes are those which consist entirely of carbonate of lime; that is, lime combined with carbonic acid gas or fixed air, in the proportion of five parts by weight of the former and four of the latter—they are all white, such as pure chalk; the Carrara marbles used by statuaries being the purest limestone in nature, and are entirely soluble in muriatic or nitric acid, which expels the carbonic acid gas with great effervescence which is a certain test of their properties and character; and when chalk or white marble is exposed to a strong red heat, as in a lime-kiln, the carbonic acid gas is driven off and the stone is converted into quick-lime, and in which state, if a piece be dropped into either of the above mentioned acids (diluted), no effervescence will occur; the quick-lime, when slaked with water, speedily falls to pieces into a fine powder with great heat, and is then termed 'hydrate of lime,' in which condition it is, by admixture with certain proportions of sand and water, converted into building mortar. Sixty-three pounds of pure native chalk will produce, upon an average, 35 pounds of lime, and when slaked with a proper quantity of water will occupy a space of about $1\frac{5}{6}$ cubic foot. A cubic foot of solid chalk weighs 95 pounds. The process of slaking will increase the weight of a cubic foot of lime from 35 to about 50 pounds, or in the proportion of 7 to 10. The carbonic acid gas driven off by the process of burning the lime-stone is gradually recovered after slaking the lime.

Thirty-five pounds of fresh-burnt chalk-lime, mixed with $3\frac{1}{2}$ cubic feet (87 pounds to the cubic foot) of river sand, and about $1\frac{1}{5}$ cubic foot of water, produces about $3\frac{1}{4}$ cubic feet of good mortar, or one-fourth of a cubic foot less bulk than the sand alone previously occupied, which is owing to the solidifying effect of the water upon the dry materials.

Pounded quick-lime measures less, and slaked powder of lime measures more in bulk than it originally occupied.

"Pure carbonates of lime are suitable for mortar to be used in dry situations or for inside work, but are unsuited for wet or damp positions, and consequently quite unfit for hydraulic mortar. In works which are much exposed to damps or to occasional floodings, when lime-mortar is chiefly to be employed, it is a good method to point all the external joints with Roman or hydraulic cement.

"Walls built with chalk-limes are most liable to 'settle'; those built with hydraulic limes settle less, and such as are built with cement, not at all."

OF WATER LIMES OR HYDRAULIC LIMES.

"These are composed of carbonate of lime, generally mixed with silica, alumina, and the oxide of iron, and with frequent indications of other matter; if the carbonate of lime be removed the residuary parts are of a clayey nature, from which fact the occasional term of *argillaceous* lime-stones is derived; they possess the peculiar and valuable property of setting in wet or damp situations, and are therefore very useful in the construction of marine works, and dock and river walls, especially when protected in front with such superior cements as puzzolana, trass, or English cement.

"Of all the English lime-stones the Blue Lias stones are reckoned the best and strongest; they are found in the British Channel, also near Watchet in Somersetshire, at Aberthaw in Glamorganshire (Wales), and at Lyme Regis in Dorsetshire. The former of these was mixed with puzzolana and used by Smeaton in the construction of the Eddystone lighthouse.

The Dorking or Mersham lime, and also the Halling lime (England), are much valued as hydraulic cements, especially the former, and are much employed in London.

All the water lime-stones are of a bluish gray, or brown color, which they derive from oxide of iron, and are usually termed stone-

limes, in contradistinction to chalk-limes. Colored chalks are commonly termed gray chalks; they are usually free from flints, and are more or less possessed of hydraulic properties.

"Most of the water lime-stones, when burned into quick-lime, so as to expel the carbonic acid gas, are of a yellowish or light brown color, so that any calcareous stone, which, after calcination, assumes a kind of buff color, may be considered to have hydraulic properties. Water limes will not bear so much sand as common chalk lime.

"Three measures of sand and one of Dorking or Halling lime make a good mortar, but blue lias stone lime requires only twice its measure of sand to produce good mortar.

"Magnesian lime-stones possess some amount of hydraulic properties, but do not make a good water lime or water cement.*

WATER CEMENTS, USUALLY TERMED ROMAN CEMENTS. *

"The best varietiesof these are produced from the isle of Sheppy, Harwich, Yorkshire, &c., and they differ chemically from water limes in having less carbonate of lime, and more silica and alumina, and practically, in not slaking with mortar unless previously pulverized; that powder balls made of these cements, calcined and mixed with water, will not swell and burst, but will set not only in air but under water, even if instantly immersed; and that these cements are always weakened by the addition of sand; and also in the necessity for their immediate use after being mixed, before they begin to heat, or they must be thrown away, as they will not bear to be re-mixed."

ON ANALYSING LIME-STONES, AND TESTING THEIR SEVERAL PROPERTIES.

"A stone supposed to be a water cement, ought to be of a bluish gray, or brown, or some darkish color, as white indicates pure lime-

* NOTE. The properties of the Sheppy cement were first discovered by Mr. Parker, who took out a patent for it under the name of 'Roman Cement,' but it is better known as Parker's cement. Mr. Frost discovered the Harwich cement, and Mr. Atkinson (architect) that obtained from Yorkshire.

stone or gypsum. From their containing silica and alumina, which are the component parts of clay, the natural cement stones, on being touched with the tongue, indicate sensibly the presence of clay, which is also detected by the smell after wetting them. They only dissolve partially in diluted acids, having a more copious sediment than any of the lime-stones.

"The first test, therefore, is to pour a little diluted muriatic or nitric acid into a glass, and drop a fragment of the stone into it. If no action takes place, it is neither a lime-stone nor cement; but if it effervesce and fall to pieces with a muddy sediment, it is probably a water-cement. To ascertain this point, break the stone, if necessary, into compact fragments, not exceeding one inch and a half in thickness, and put two or three of these into a common fire-place, first heating them gradually, that they may not burst into too many small pieces, and keep them exposed to a full red heat for about three hours. At the end of this time, take one of your specimens out of the fire, and put a small fragment of it into a glass of diluted muriatic or nitric acid. When the stone is burned enough, that is, when all the carbonic acid gas has been driven off by the heat, no effervescence will take place in the acid. A moderate effervescence will show that it is a little under-burned, but violent effervescence will prove that it is very imperfectly burned, and it should therefore be put into the fire again.

"Care must be taken not to over-burn the cement, which would always injure if not entirely spoil it; this fact may be known by its changing to an unnatural dark color, and which is a proof of incipient vitrification; for, by excess of heat, all the natural cement stones may be fused into a dark-colored glassy substance resembling the volcanic product called *obsidian*.

"If, therefore, the calcined cement stone does not effervesce with acids, and if at the same time its proper color be not changed to a darker one on taking it out of the fire, it will prove that it is properly burned.

"The next process is to pound the perfectly calcined specimens to an impalpable powder, which state is ascertained by its not feeling gritty when rubbed between the fingers and thumb. This is an important condition of natural and artificial cements, for their properties are much deteriorated by not being finely powdered after calcination. You must then proceed to mix a small quantity of the powder with a moderate quantity of water, upon a slate or slab, into a paste, with a spatula or knife, and then form it into a ball by turning it between the palms of the hands, when it will become warm, and if it be a good water-cement it will not only set or harden in the heating, but if put into a vessel of water will become more indurated. Good cement will harden under water, even if put in while wet, but it is better to wait and let it cool a little before you put it in.

"The setting of these cement balls will be greatly retarded by using an excess of water in their mixture, the best proportion of which appears to be one-fourth part of water to one of cement. During the process of setting, they always throw out a vapor so long as the heat continues.

"The Sheppy cement stone is usually found in boulders or round nodules, and when dry is of a light brown color.

"The Harwich cement stone is obtained in larger masses, and is of a dark bluish brown color. When properly burned, the former is of a light brown, and the latter of nut brown color. When the calcined powder of each is mixed with water for use, both mixtures are brown, but the former is much lighter than the latter, which approaches to blackness.

"Since cement from the kiln will not slake even with water, much less by the action of the air alone, it might be preserved for a long time in a dry room as I have proved by experiment; but calcined cement being useless until pulverized, which process is always performed by the manufacturer in a mill, in which state water and the atmosphere is enabled to act upon it.

"Calcined cement powder, when mixed up for use, recovers (like

the lime mortars) in time the whole of the carbonic acid gas, previously thrown off by the fire, and is brought back to its original chemical state. And old cements and mortars if re-burnt, calcined, and pulverized to powder, will produce a material nearly as good as from the natural stone.

"Cement powder exposed to the air, especially if damp, also gradually recovers the carbonic acid gas, and becomes injured and eventually spoiled; for which reason it is always kept in tight casks or bags, but when the cement becomes damaged or stale, it may be recovered or converted into good cement by re-burning it, the practicability of which may be ascertained by burning some stale cement powder in a crucible, in a common fire-place; but if any considerable quantity should be required to be restored, it must be first mixed up with water into balls or convenient sized lumps, and allowed sufficient time to set, or harden before being re-burnt. If, however, the cement-powder should be too stale for this purpose, let a small portion of fine clay, not exceeding one-tenth part (by measure), be added to it, in making these lumps, which will cause them to hold together in the kiln, without materially injuring the quality of the cement.

"The most powerful water cements are like limes, partially decomposed by and soluble in water when first prepared for use, but the injury is too insufficient to affect the solidity of structures in which it is employed.

"Cement, soon after it is mixed or applied, throws out an efflorescence at first, as is observable in the fronts of buildings, when first stuccoed therewith, and is considered a criterion of good quality. This efflorescence, when viewed in the sun or a strong artificial light, presents the appearance of bright crystals.

"Whilst water cements, and water limes are analogous in their component parts, and general properties, there is great distinction between them for the purposes of *hydraulic architecture*, inasmuch as the setting process at the surface comes so much sooner to perfection in the former than in the latter, that the water which after this period

ceases to act perceptibly upon either, has not time to injure the external joints of the cement, while it makes a considerable impression upon the lime; in this consists the chief difference between them, and it constitutes their relative use and value.

"There are two properties of cement which ought to be fully understood. 1st. That it only sets rapidly when made up in small parcels or thin joints, as rapid induration takes place near the surface only, extending slowly towards the centre, where it may remain imperfect to a very long time. This property it has in common with lime mortars and concrete. 2d. Cement is always weakened by sand, no matter how small the proportion of that ingredient may be, so that if both materials were equally cheap, it would be best to dispense with sand altogether in using cement as mortar for building walls, but not in using it as a stucco for incrustations.

"With reference to the quantity of sand which should be mixed with cement for constructive purposes, where strength and durability are desired, both experience and experiments clearly show, that not more than two measures of sand to one of cement powder ought to be employed on any work, and that when very important operations are involved, five parts of sand to four of cement powder ought to be used, or what is better, an equal proportion of each ingredient, as too much sand injures the cement by retarding its drying or setting, and renders it too friable; but with limes it is different, for they will bear two, three, or even more measures of sand to one of lime, without much deterioration. Upon the whole, cement sets most quickly and unites itself more powerfully to bricks or stones, when it is perfectly pure or unmixed with sand, provided the joints be thin, that is, not exceeding half an inch in thickness.

"The construction of the Thames Tunnel satisfactorily established the character and superiority of the cement, and without the aid of which the work could never have been carried on to completion, or any lengthened period of durability assured. The foundation and lower portions of the brick-work, having been laid in a compost

of equal proportions of cement and sand; and the piers were built with one measure of sand to two of cement, and the arch work with pure cement only.

"Lime expands by admixture with water, and readily attaches itself to the particles of sand, which increase the bulk and add much to the strength, whereas cement does not expand, and is weakened by the addition of sand; and whilst one measure of good calcined lime powder will take seven or eight measures of gravel to form a good concrete, the cement will require three measures of it, to mix with the above quantity of gravel or sand to produce concrete of an equal property. Hence cement should never be used for making concrete. But for the purpose of building brickwork, it is as well to mix the cement with a moderate quantity of sand, as the cost of the work is thereby diminished, and the joints will become quite as hard as the bricks themselves. Pure cement should always be employed for the most important works, or in particular portions of them, and it is indispensable for the linings of cisterns or tanks, and the coating of casemates, as it prevents leakage, and renders the latter perfectly dry, but it cannot be depended upon for such like purposes if mixed or adulterated with sand; and great care must be taken in the application of the cement, to have it firmly compressed and consolidated when laid on, to prevent cracks or fissures; the neglect of plasterers in this precaution being the chief cause of the defects in exterior and other incrustations where this cement is employed. This material mixed with a due proportion of sand, and applied in a liquid state, forms a most excellent groat."

ON BLACK ROCK OF QUEBEC.

"At the suggestion of Capt. Baddeley, R.E., the author of the treatise now under notice (Col. Pasley, R.E.), by order of the British Government, made some experiments upon its character and qualification as a water (or hydraulic) cement, and found its properties to be very satisfactory, although it was comparatively very slow in sett-

ing, but in the end it acquired a very stony hardness. For tide work he considered it would be necessary to mix it with boiling water to expedite the setting."

ON ARTIFICIAL WATER CEMENTS AND ON THE ESSENTIAL COMPONENTS THEREOF

"Natural water cements being chiefly composed of carbonate of lime, silica, alumina and the oxides of iron, it appeared that next to the carbonate of lime or chalk, which is indispensable, silica and alumina were the most important ingredients, for these together made a water cement without the iron, whereas the iron never succeeded without them, notwithstanding which, it was of great use, since it caused them to set more quickly, and at the same time imparted a superior degree of compactness and hardness; but in all cases it is imperative that all the solid ingredients be well burned, calcined and reduced to an impalpable powder, and the moist ones must also be reduced to the finest possible state before being burned."

In order to establish these facts the author undertook the following experiments:—

"EXPERIMENT 1st. Carbonate of lime, silica, alumina, with other metallic oxides, with the addition of the peroxide of iron—these occasionally formed a good cement, but the success of this mixture is very precarious. The addition of the oxides of manganese or of red lead always formed good cements with the same ingredients.

EXP. 2d. Carbonate of lime, silica, alumina, with the carbonate of magnesia. On mixing measures of pounded chalk, two measures of pipe-clay, aud from one to five measures of the carbonate of magnesia together—the result was an excellent artificial cement. This cement when moderately burned was of a handsome white color; but when burnt rather more, it assumed a darkish slate color, but in either case it was equally good.

"Carbonate of magnesia is a highly favorable ingredient in water cement, producing the same effect as protoxide of iron, or it may be said to be superior to it, or to any other metallic oxide, inasmuch as the carbonate of magnesia will sometimes combine with the carbonate of lime, alone, into a good water cement, which none of the metallic oxides are capable of effecting.

"Exp. 3d. Chalk and blue alluvial clay. This mixture of pounded chalk and blue clay; of which the former ingredient supplies the carbonate of lime, and the latter, the silica, the alumina, and the protoxide of iron, was successful, and is here placed among the quadruple compounds. Having tried various proportions of the above ingredients, the following, which most resembles the Sheppy cement in its qualities, was adopted, viz., five measures of chalk to two measures of moist clay. Three measures of chalk to one of clay will also make a good water cement, but not equal to the former proportions. An excess of chalk such as three and a half, four or five to one, spoils the mixture as a "water cement," but converts it into a "water lime." A smaller portion of chalk, on the contrary, such as two to one, makes a very good water cement, and even one and a half measure of chalk to one of clay, makes a good cement, but one that sets slowly and with moderate heat, for as the quantity of chalk is diminished, so is the heat of setting, whilst the period required for that process is prolonged."

CONCLUSIONS DRAWN FROM OTHER EXPERIMENTS.

"That alluvial clay is brown at the surface, where it is exposed to the air, and that this brown part will not form a water cement. That blue clay fresh from a river, which forms an excellent ingredient for an artificial water cement, loses this property when it becomes stale by exposure to the air, which also deprives it of its color.

"That repeated washings spoil alluvial clay.

"That chalk and fine brown pit clay make a good cement.

"That tile-dust, slate-dust, and Fuller's earth failed; and that as

none of these are plastic, which property seems necessary in clay as an ingredient for a water cement—

"That Fuller's earth is much improved, and rendered plastic by repeated washing.

"That hard stone if used as an ingredient for a water cement, must be burned twice, first in its natural state, and afterwards mixed with clay.

"That lime and clay burned separately failed in making an artificial cement, on immediate immersion, but may be useful for many hydraulic purposes, though inferior both to the natural and artificial cements."

Then follows a series of experiments to ascertain by what additional substances, the best natural cements may be spoiled, from which the following conclusions are deduced, viz.:—

"That salt is very prejudicial to brick earths.

"That the carbonate of magnesia was the only substance which did not spoil the Sheppy cement.

"That the latter ingredient is itself a water cement, but a slow setting one.

"That all the author's experimental cement which had succeeded in setting under water, also resisted the severest frosts, quite as well as the natural cements, after rigorous tests to which they were exposed in the winter of 1829—30.

"That the best cements, though perfectly 'frost-proof,' may be injured by frost, if applied as stucco in an injudicious manner."

VARIOUS RECIPES FOR CEMENTS, MORTARS, ETC.

FOR BUILDING AND INCRUSTATIONS.

A strong mastic cement for coating walls, &c., is prepared as follows: 20 parts of clean river sand, 2 parts of litharge (red lead), and 1 part of quick-lime, mixed into a thin putty with linseed oil.

Dahl's cement for covering fronts of buildings consists of linseed oil, rendered dry by boiling with litharge, aud mixed with porcelain clay in fine powder, or pipe-clay well ground, and colored with ground bricks or pottery. A little oil of turpentine added, to thin this cement, aids it in its cohesion to brick, stone, &c.,

Hamlin's cement is composed of fifty measures of siliceous sand fifty of lime marl, and nine of litharge, ground up with linseed oil. This material has been in much use and repute in England and elsewhere.

Leardet's (or, as it is commonly called, "Adam's") oil cement or stucco, is prepared in the following manner: for the first coat, take 21 pounds of fine whiting, or oyster shells, or any other sea shells calcined, or plaster of Paris, or any other suitable calcareous material, calcined and pounded; add white or red lead at pleasure, deducting from the other absorbent materials in proportion to the weight of the red or white lead added, to which put four quarts (beer measure) of oil, and mix them together in a grinding mill, or in any levigating machine, and afterwards mix and beat up the same, well, with 28 quarts of sand or gravel, or of both, mixed and sifted, or of pounded stone or marble, or any solid and suitable material.

For the second coat, 16 ½ pounds of superfine whiting, or oyster shells, &c., as for the first coat, 16 ½ pounds of white or red lead, 6 ½ quarts of oil, and mix them together as before described; add 30 quarts of fine sand, gravel, &c., as before noted, and mix and beat them up well together; varying the proportion of sand or gravel, &c., as the

nature of the work may require. In preparing this composition the best linseed or hempseed or other proper oils, suited for the purpose, must be employed, either boiled or raw, with such drying ingredients as the nature of the work, climate, season, or other circumstances may demand; and in some cases, bees-wax may be substituted for oil. All the absorbent and solid materials must be kiln-dried.

This cement is applied in the usual manner, but previous to laying it on, it may be proper to wet the surface on which it is to be laid, with the same sort of oil and other ingredients which have passed through the levigating machine, reduced to a more liquid state and applied with a brush, in order to make the composition adhere the better.

This composition admits of being modeled or cast in molds in the same manner as statuaries, plasterers, &c., model or cast their stucco work. It also admits being painted upon, and adorned with landscapes, figures, &c.

A good cement is prepared from equal quantities of powdered glass, sea-salt, and iron filings, mixed with burnt loam, which becomes very hard and durable.

Beavan's mortar, or building cement, is composed of marble, flint, chalk, lime and water, and when dry is capable of a high polish. Its proportions are, equal parts of marble, flint and chalk; pulverized, mixed together, and passed through a very fine sieve; add to this one part of lime which has been slaked three months, and sufficient water to make the whole into a thin paste; and in this state it is to be applied over a coarse ground (or previous coat), as thin as possible, and rendered smooth on the surface; and when dry may be polished by Venetian talc. If buildings are to be covered with it, a preparatory rough ground should be attached, formed of river sand and lime.

Venetian cement, used in the Italian provinces for covering floors, terraces and roofs of houses, the secret of which is not precisely known, is believed to be compounded of plaster of Paris, sulphur, resin, pitch, and spirit of turpentine, or wax, mixed and applied hot.

Smeaton's cement, used in the construction of the far-famed Eddystone lighthouse, in the British Channel, was composed of equal quantities of Puzzolana and Aberthaw lime; this mixture was calculated as best able to withstand the utmost violence of the waves which are continually beating, and oftentimes with violent shocks, the substructure of the building; and truly has that conjecture been verified by the test and experience of many years and sundry storms.

Two bushels of slaked Aberthaw lime, one bushel of Puzzolana, and three of clean, sharp sand, will form a good water-cement.

Dutch trass, terras, or tarras, or as sometimes called in Holland, *wakke*, is a basaltic mineral, found in the Low countries, and abundantly used in the construction of mounds, weirs, and other aquatic works. This celebrated mortar is made by covering a previously prepared mass of quick-lime of about a foot in thickness (and sprinkled with water), with an equal quantity of powdered terras, and then left for two or three days, after which, the quantity required for immediate use is separated from the bulk, and beaten up to a proper consistency.

One measure of quick-lime, and two of slaked-lime, in powder, and one of terras, well mixed and beaten together to the consistence of paste, with as little water as possible, forms the terras mortar in general use; and a cheaper kind is made by mixing two parts of slaked lime, one of terras, and three of coarse sand together. These cements indurate very quickly under water and remain very firm.

The trifa stone, which, when ground, forms trass or terras, contains 57.0 silica, 16.0 clay, 2.6 lime, 1.0 magnesia, 7.0 potash, 1.0 soda, 5.0 oxide of iron and titanum, and 9.6 water; it is found abundantly in the north of Ireland, among the schistoze formations on the banks of the Rhine, and at Manheim in Bavaria.

The fatter the lime, the less of it must be added to the trass to make hydraulic cement; the mixture should be made extemporaneously, and kept dry till used. When it hardens too soon (as in twelve hours) it is apt to crack, but if it takes six or eight days to indurate, it

is better; through the medium of water, silicates of lime, alumina, clay, and the oxide of iron are formed, which soon become hard.

"Beside the two volcanic products just described, all lime-stones which contain from 20 to 30 per cent of silica are fitted for hydraulic cements; but much depends upon the proportion of silica present, and the physical structure of all the constituents.

Meagre or poor lime-stones are best suited for hydraulic mortar, such as contain from 8 to 25 per cent. of foreign matter, such as silica, alumina, magnesia, &c.; these, though calcined, do not slake when wetted; but when pulverized, will absorb water without heat or swelling, and form a paste which will harden under water in a few days, but will never become greatly indurated by simple exposure to the air.

All sorts of lime can be made hydraulic by mixing slaked lime with solutions of common alum, or sulphate of alumina; but the best method consists in employing a solution of silicate of potash (called liquor of flints, or soluble glass), to mix with the lime, or lime and clay. Also by adding silica and alumina, or merely the former to good fat lime, a water-cement may be artificially formed; and likewise by adding to lime or other natural productions which contain silicates—puzzolanas, trass, pumice-stone, basalt, trifa, slate clay, &c.

Ground *felspar*, or clay, if previously calcined with the lime, will form an hydraulic cement.

Beton (French), used for constructing marine works, consists of 12 parts of puzzolana, or Dutch trass, 6 parts of sand, 9 parts of unslaked lime, 13 parts of stone fragments, about the size of an egg, 3 parts of tile dust, cinders or scales from a forge; the whole well worked and beaten together.

A composition for incrustations may be formed of lime-stone, road-drift, sand, or similar substances, with the powder of burnt-bones; these ingredients are to be powdered, mixed together and heated in an oven, and while hot to be mixed with one-fourth part of tar, pitch, or resin, and applied warm; this will be found a good covering for roofs, floors, terraces, &c.

Plaster of Paris, with an admixture of one tenth part of rust of iron, or iron scales or filings, makes a water-cement which sets very quickly and is of great hardness, and if boiled potatoes be incorporated with mortar of lime and sand or with mortar containing burnt clay, these compositions will be much improved.

A composition said to equal Roman cement is made by dissolving three pounds and a half of sulphate of iron, and mixing them with a bushel of lime, and half a bushel of fine gravel sand, previously made into mortar.

Parker's Roman cement, for incrustations and general building purposes, is a composition forming an artificial stone, and being impervious to water is very valuable. This material, when incorporated with an equal quantity of clean sharp grit sand, well beaten up with a sufficiency of water, and applied quickly, forms a handsome and durable covering for fronts of houses; and one bushel of the cement, with the addition of sand, &c., is considered sufficient to cover about four square yards of surface.

Ancient Maltha. The Roman and Greek architects gave the term of maltha to a calcareous cement used as stucco, and this and the term *mastic* are given to various compositions.

The mixture of milk with lime and sand is said to have constituted the maltha of the Greeks; and we learn from Pliny, that Roman maltha was made by mixing fresh-burnt lime, slaked with wine, and beaten in a mortar, with hog's lard and figs. This composition is reported to possess great tenacity, and acquires the hardness of granite.

Another kind was made of powder of slaked lime, mixed with bullock's blood and powdered scales of the gray oxide of iron.

Previous to applying the maltha, the surface of the wall or ceiling was smeared over with oil to make the composition adhere.

Dr. Shaw gives the following particulars of a species of maltha which the inhabitants of Tunis and of other places in Africa use for incrustations, &c. One measure of sand, two of wood-ashes, and three of sifted lime powder are mixed together with a very little water,

and after this mixture has been well beaten, a little oil is added; the beating is then resumed, and continued for three or four days occasionally, during which, the proper degree of softening is preserved by alternately adding small quantities of water and oil. In a short time after its application it acquires the hardness of stone.

A cement of a gray color, found upon examination to be composed of an admixture of unslaked lime, pulverized charcoal, and powdered sandstone, was discovered in the construction of a mausoleum of some of the Tartar princes. The spaces between the bricks were about an inch broad, and the cement had acquired such a solid consistence that it was found easier to break the well-burnt bricks than to separate or detach the cement.

A composition for mouldings, &c., is prepared from two pounds of powdered whiting, one pound of glue, mixed with half a pint of oil, and thoroughly incorporated in a metal vessel by means of heat, and then well beaten on a stone with whiting, till it has acquired the necessary consistence and toughness. It is kept under moist cloths until used. The ornaments or mouldings when cast and dry are affixed to the surfaces by means of glue or white lead.

A delicate cement for small work, is made by heating a pint of milk to the boiling point, and adding vinegar till the curd separates, then straining off the whey, which must be beaten up with the whites of four or five eggs, gradually adding the whey again. When the whole is well mixed, sifted quicklime is to be stirred in until the consistence becomes like a thick paste. The prepared liquid alone may be kept, if closely corked up, but the lime must only be added when required for use. This composition resists the action of fire and water, and is chiefly used to replace deficiencies in small works, and to fasten fragments together, which it unites firmly.

A cement for stopping holes and cracks in marble or stone, and for veneering marble, for inlaying and mosaic work, is made of a pound of bees-wax, sliced, melted with a quarter of a pound of resin, powder-

ed, to which add an ounce, each, of chalk and brick-dust, both finely powdered, the whole to be well boiled and mixed up together. This cement must be used hot, and the substance to which it is applied must be previously heated.

The cold cement for the like purpose or for mending earthenware, &c., and which is reckoned a great secret among workmen, is made by grating a pound of old Cheshire cheese, with a bread grater, into a quart of milk, in which it must remain fourteen hours, stirring it frequently, a pound of unslaked lime in powder must then be added, and the whole well-beaten up, and finally add the whites of twenty or thirty eggs, beaten up with any coloring matter desired, and let the whole be well mixed and beaten up together.

The hot cement is made of resin, beeswax, brick-dust, and chalk boiled together. The bricks or other substance to be united, must be heated, and their surfaces rubbed together with the cement between them, as carpenters make a glued joint in boards.

Frost's water cement is composed of carbonate of lime, calcined at a heat not exceeding that at which cast-iron softens, and cooled without acccss of atmospheric air or moisture, acquires the property of quickly hardening under water, and mixed with silicious sand and water, forms an artificial Puzzolana, or Roman cement.

Dobbs' cement for water-proof purposes, is composed of carbonate of lime (burnt as for common plaster) mixed up with water, clay loam, shale, road drift, metallic oxides, ores, sand, or any other earthy substance which will bear a sufficient heat for calcination. The whole of these ingredients are then to be reduced to a fine powder, mixed with a water, and left in proper vessels till it has subsided. The water is then to be poured off and the plastic materials formed into square pieces and dried, after which they are to be subjected to the heat of a lime-kiln or stove, and lastly mixed with the lime and water for the intended purposes.

A good incrustation cement is made with one hundred parts of quick lime, five of white or colored clay, and two of yellow ochre; it

forms a cement which is tenacious, and remains unchangeable when exposed to the weather. The process of its manufacture is thus: The lime must be first slaked with a small quantity of water, more of which must afterwards be added till of the consistence of cream. White clay is at the same time mixed to a similar condition, and after remaining some time apart, the two solutions are carefully mixed together. During the continuance of this mixture in a tub for twenty-four hours, it should be frequently stirred, and a portion of yellow ochre added to give it an agreeable color. Walls covered with this cement have remained exposed to the weather for years, without injury.

M. Berthier is of opinion that with one part of common clay, and two parts and a half of chalk, a very good hydraulic lime may be made which will set as quickly as Parker's cement. He concludes that a lime-stone, which contains six per cent of clay, affords a mortar precisely "hydraulic."

Lime possessing from fifteen to twenty per cent of clay, is very hydraulic, and when from twenty-five to thirty, it sets almost instantly, and may therefore be held to be a perfect Roman cement. But an argillaceous lime-stone, which, when slaked, increases its bulk from one to three parts in ten, and which when in the form of slaked paste, will take from one hundred to one hundred and sixty measures of sand, will afford at a moderate cost, a cement well fitted to resist atmospheric changes, and constant exposure to a running stream.

A little manganese added to mortar imparts the property of hardening under water, and lime-stone is frequently found combined with this mineral, which gives it a brown color when burnt.

The essential constituents of all good hydraulic mortars are caustic lime and silica, the hardening of which under water merely consists in their chemical combinations, through the medium of water, producing a hydrated silicate of lime. Quartoze sand, however finely powdered will form no water mortar with lime, but if the powder be

ignited by the lime, it will be rendered fit for hydraulic works.

Bituminous lime-stone dried, ground, sifted, and mixed, with about its own weight of melted pitch or coal tar, may, when in a semi-fluid state be moulded into blocks or slabs, and be applied for floors of terraces, balconies, roofs of houses, or linings of tanks and reservoirs, conduits, drains, &c., but when laid, the joints must be run together with hot irons. The terrace floor must be previously covered with a layer of *plaster-of-paris* or common mortar, laid to the required slope or level, about an inch to the yard. It weighs about 144 lbs. to the cubic foot, consequently one foot square, and one inch thick will weigh 12 lbs.

RECIPES

FOR MANUFACTURING AND DOMESTIC PURPOSES.

Iron-rust cement: 100 parts of iron borings or filings, powdered and sifted, and mixed with one of sal-ammoniac, and when applied must be mixed and well incorporated together, with as much water as will give it a pasty consistency; or 4 parts of fine borings, 2 parts of potter's clay and 1 of powdered potsherds, mixed as above. This cement is good for making joints &c., to ironwork, and if allowed to concrete slowly becomes very hard.

Plumber's cement: 1 part of black resin and 2 parts of pulverized and sifted brick-dust, well incorporated together with a melting heat.

Coppersmith's and engineer's cement: Boiled linseed oil and red lead, mixed into a putty; or bullock's blood and quick-lime.

Diamond cement, for mending china, glass, porcelain, &c., is composed of isinglass, soaked in water till soft, then dissolved in proof-spirit, to which are added a little gum-resin, ammoniac, or galbanum, and resin mastic, each being previously dissolved in a minimum of alcohol; and when applied must be gently heated, in order to liquify it, and when not required should be kept in a well-corked bottle.

Other cements for the like purpose: Gum shellac dissolved in alcohol, or in a solution of borax, makes a good cement.

White of eggs (albumen), mixed with finely powdered quick-lime,

forms a good cement for joining substances which are not exposed to much moisture.

Skim milk cheese, cut in slices, and boiled to a gluey consistence in a quantity of water, and then incorporated with quick-lime on a slab with a muller; is applied to mend broken stone-ware, and when cold unites very firmly.

Melted brimstone (sulphur) used either alone or mixed with resin and brick-dust, makes a tolerably good and cheap cement.

Jeweller's cement is composed of resin, beeswax, and finely sifted brick dust, and is in use amongst goldsmiths, jewellers and engravers, to fix metals, stones, &c., to be engraved or operated upon, firm to the block.

Carpenter's cement: Take equal quantities of pounded resin and beeswax, mixing them together over a slow fire, during which process add as much powdered chalk, yellow ochre, or burnt ochre, as will produce the required color, and when well incorporated together, apply hot; or—

Take fine saw-dust of the wood you wish to imitate, and macerate it in water for two or three days; then pour off a part of the water, and boil the residue until it becomes smooth and pulpy. Keep it well covered up for use, and when required, mix as mnch glue with it as necessary. These cements are very useful for stopping up flaws in wainscotting, and for other purposes.

A cement for fixing mouldings, fillets, ornaments, &c., can be made by dissolving isinglass, and adding glue to it which has been soaked twenty-four hours, and straining the compound through a fine sieve, or coarse cloth.

A cement for closing and repairing pipes of subterraneous aqueducts, is composed of pulverized tobacco-pipe clay, mixed with a large quantity of pulverized flocks, tempered with linseed oil, and well beaten into a stiff paste.

A cement for fastening the receiver of an air-pump to a metallic plate, is made with equal parts of beeswax and turpentine (for winter

use), or three parts of beeswax to two of turpentine, for summer use.

Chemist's cement, for repairing chemical glasses or vessels, and which will bear the fire, is made with equal quantities of wheat flour, fine powdered Venice glass, pulverized chalk, with half the quantity of fine brick-dust, a little scraped lint, and the whites of eggs, well and properly incorporated together. This mixture is to be spread thinly but evenly on linen cloth, and then applied to the fractured parts of the glass, and the whole should be well dried before subjected to fire; or old varnish is said to answer the same purpose.

Electrical cement, for electrical purposes, is compounded of two pounds of resin, two of beeswax, and one of powdered red ocher, the whole mixed and melted together, and kept close for use; or five pounds of resin, one of beeswax, one of red ocher, and two table-spoonfuls of plaster of Paris, well melted together.

A bituminous cement: Sixteen parts of whiting, sifted and thoroughly dried by a white heat, the like quantity of black resin, and one part of beeswax, to be added to the former ingredients while cool, stirring the whole together while cooling.

A cement for uniting voltaic plates and wooden troughs, is composed of six pounds of resin, one of red ochre, half a pound of plaster of Paris, and a quarter of a pound of linseed oil. The ochre and plaster of Paris must be previously calcined, and added to the other ingredients when in their molten state, and the thinner the stratum of cement applied, the stronger will be the joint.

Statuary's cement, for joining alabaster, marble, porphyry and other stones, is prepared as follows: Melt two pounds of bee's wax and one pound of resin together; add one pound and a half of the same material, pulverized, as the body to be cemented is composed of, and stir them well together; let the mass be warmed together, and when applied, the body or matter to be cemented, should be heated, The required color can be obtained by varying the proportions of the powdered matter, and the mass of bee's wax and resin.

Steam cement. This is not only useful for cementing different

parts of hydraulic and steam engines, but also for repairing broken stone, &c. It consists of boiled linseed oil, litharge, and red and white lead, mixed to a proper consistence, aud applied on each side of a piece of flannel previously cut to the shape of the joint of iron or other substance, and put between the pieces before being screwed together, or hammered, or "brought home" as the workmen term it. By this means a close and durable joint is made. Care must be taken not to leave the mixture too thin with oil, and as the white lead does not dry so quickly as the red, more of the latter ought to be used. When the fittings will not admit the substance of flannel, linen, paper or thin pasteboard, may be substituted.

The following cement answers well for joining broken stones of the largest kind, and stone joints set with this, never leak or want future repairs; and if the stone be thick, not more than an inch next the water need be filled with the cement, the rest may be done with common mortar: Two ounces of sal-ammoniæ, one ounce of flower of sulphur, and sixteen ounces of cast-iron filings or borings; mix them in a "mortar," and keep the powder dry. When this cement is wanted, take one part of the above, to twenty parts of clean iron filings or borings, and mix them intimately, and beat to a powder in a mortar. When mixed to a proper consistence with water, apply it with a wooden or iron spatula.

This is the cement used in the filling-up and clasping the joinings of Southwark cast-iron bridge, built over the river Thames (London) by the late Sir John Rennie. The chemical action of all these ingredients on one another causes the whole to unite in a hard homogenous mass.

Flooring cement may be made of two-thirds of lime, and one of coal-ashes, well sifted, added to a small quantity of clay; then mix the whole together with water, temper well, and make into a heap, let it remain for a week or ten days, then temper again, heating it until it acquires a proper tenacity and consistency.

The surface upon which it is to be applied being made perfectly

level or smooth, lay the composition on, about two and a half or three inches thick, working it smooth with a trowel. If a better floor be required for superior apartments, cover this first layer with another, made of the lime of rag-stones, well tempered with whites of eggs, laid on about half an inch thick, before the first covering or layer becomes too dry.

When the whole is thoroughly dried, and rubbed with a little oil, it will be as smooth as polished marble. This cement is also adapted for roofs and walls.

RECIPES.

The following recipes are from Colonel Fanshawe's memoranda, and remarks on hydraulic mortars, descriptive of different sorts used at Water Point, Gibraltar, in the year 1790—1 :—

1st. Coal-ash mortar. This consisted of lime two and a half measures, sand two and a half, coal-ashes two and half, Puzzolana one and a half, and smith's cinders one and a half, the proportion of lime to the other ingredient, thus being one to three and a half.

2d. Dutch terras mortar. This was formed of equal parts of lime and trass, by measure.

3d. Puzzolana mortar, which consisted of the like proportions of lime and Puzzolana.

4th. Puzzolana mortar for lining cisterns and coating the roofs of casemates. This consisted of slaked lime sixteen measures, Puzzolana eight, sand five and a quarter, beaten glass four, and smith's cinders four, the proportion of lime to the other ingredients being as one to one and two-thirds nearly.

NOTES ON PUZZOLANA.

Col. Pasley draws the following inferences from various experiments upon the effects of Puzzolana, when mixed with other cementitious matters.

1st. That Puzzolana is very injurious to cement.

2d. It imparts to chalk-lime the important property of setting under water and to increase its adhesiveness to a moderate extent when mixed in the proportion of two measures of Puzzolana powder to one of lime paste; but it increases the resistance of this lime in a most extraordinary degree, nearly six-fold, rendering it in seventeen days nearly double of the resistance of the best concretes and mortars made of the same lime, mixed with gravel and sand alone, though eight to twelve months old and upwards.

3rd. That the effect of Puzzolana on common chalk lime, mixed with sand, is highly beneficial, the usual proportion of the powder employed is one measure to one of lime, combined with various proportions of sand, for which Smeaton's rule, that the latter shall not exceed two measures, when the lime alone, without the Puzzolana, will bear three measures of sand, is probably the most judicious. By our experiments, it appears that one measure of sand to one of Puzzolana powder, and one of chalk-lime paste, produces the strongest Puzzolana mortar with that species of lime; that one additional measure of sand diminishes the adhesiveness of this mortar in a slight degree, not exceeding 10 per cent., but that it diminishes the resistance by 60 per cent.

4th. Its effect upon a strong hydraulic lime, such as Blue Lias lime, is to increase its adhesiveness, and when mixed in the proportions of two measures of the Puzzolana powder to one of lime, it increases its resistance also, but one measure of each would be the utmost proportions that could be recommended in practice.

5th. Its effect upon a weak hydraulic lime is favorable, and for works under water it would not be prudent to use such limes without an admixture of it.

M. VICAT'S RULES FOR JUDGING OF THE QUALITY OF NATURAL OR ARTIFICIAL PUZZOLANAS.

He recommends testing them by acids, and in water, and observes:

1st. That those which are not acted upon by acids, and have no action

on lime-water, are inert. 2d. That those which are moderately acted upon by acids, and which act very moderately in lime-water, have little energy. 3rd. Those which are powerfully acted upon by acids, and which are very active in lime-water, are energetic.

M. Baggi, of Gottenburgh, made use of a very hard, black, schistous rock, which he burned until it lost its hardness, and afterwards pulverized it, in which state it made, when mixed with lime, a good hydraulic mortar.

Count Chaptal calcined the ochrey clays of Languedoc, (France,) of which he made an excellent artificial Puzzolana; and subsequently M. Mason experimented upon the same description of clay, and converted them into Puzzolanas, which were tried as "betons," by sinking casks filled with them in the Seine, and which, after six months' submersion, were found to be extremely hard.

General Treussart states that a mixture of common lime with sand and brick-dust (pounded brick is probably meant), in equal parts, forms a hydraulic mortar requiring a breaking weight of from 221 to 331 lbs. avoirdupoise, which he considers sufficient for general purposes, but for more important works he thinks that a resistance of from 331 to 441 lbs. is desirable, for which purpose the clays suited for potteries should be selected, which are to be treated by burning, &c., as before described.

He also remarks that artificial Puzzolana, formed of bricks exposed to a draft of air while being burnt, will set in three or four days, whereas, that formed of similar bricks, equally well burned, but not so exposed, may not set for ten, twenty, or even thirty days, and yet may form good hydraulic mortars in time. He says that he has observed, that the strength of artificial Puzzolana may generally be judged by its quickness in setting.

He also tried other experiments upon *trass*, and found that mortar made of one measure of common lime, mixed with two measures of sifted trass, was nearly twice as strong as the mortar made of the same lime, mixed with coarse trass in the same proportion, their re-

sistence being 463 and 232 lbs. respectively; and he also ascertained that wetting trass did it little or no harm, and he is of opinion, that neither trass nor any sort of artificial Puzzolana nor natural Puzzolana can possibly be injured by exposure to the weather.

M. VICAT'S OPINION OF THE BEST COMBINATION OF VARIOUS LIMES WITH OTHER INGREDIENTS FOR THE COMPOSITION OF MORTAR.

In order to obtain hydraulic mortars capable of acquiring great hardness under water, or in situations always moist, he recommends weak hydraulic limes to be combined with energetic Puzzolanas, and that hydraulic limes may be combined with Puzzolanas of little energy, but that first-class hydraulic limes may be mixed with inert substances such as sand, whether siliceous or calcareous, and also with the slag of forges, &c.

To obtain mortars or cements capable of acquiring great hardness in the open air, and to resist rain, heat, and severe frosts, he is of opinion, that fat limes are unsuited for such purposes, nor can weak hydraulic limes accomplish it in a satisfactory manner, but that ordinary and eminently hydraulic limes will succeed if mixed with any clean sand, quartoze dust or with the powder of hard lime-stones or other inert substances.

Of mortars to be used under water he says that the proportions of sand and other ingredients used with different sorts of lime, must vary according to circumstances, but as a general rule he states that *arenes psammonites* and *clays* will do with a smaller proportion of lime than other substances generally, for in measuring them in the state of dry powder, they require of fat lime-paste, slaked by the common method, from 15 to 20 per cent; of moderate hydraulic lime from 20 to 25 per cent; and of hydraulic lime, from 25 to 30 per cent. That the energetic or very energetic Puzzolanas require, under the same circumstances, of fat lime from 30 to 50 per cent, and of moderate

hydraulic lime from 40 to 60 per cent; and that silicious any calcareous sands require of hydraulic or eminently hydraulic lime from 50 to 66 per cent. As a general rule it is better to err by using too much. than too little lime in such mixtures, for excess of lime causes them to adhere better to stone, but if to be used alone, then the just proportions attain the greatest induration.

M. VICAT'S MODE OF PREPARING ARTIFICIAL HYDRAULIC LIMES.

Wherever good hydraulic limes are to be found on the spot, or can be procured at a moderate expense, M. Vicat recommends using them, but when only common limes or inferior hydraulic limes are to be found, he converts them into water-setting limes, by the following process:—

Burn the lime in the usual manner, and let it slake or fall down into powder by spontaneous slaking in the air under cover, then mix the slaked lime with a certain quantity of gray or brown clay, or simply with brick earth into a paste with water, and form it into balls, which are to be first dried and then baked in a kiln. He gives the following proportions of clay to be used:—

Very fat common limes, such as absorb a great quantity of water in slaking, and which are pure or nearly so, as common chalk, will bear 20 per cent of clay; for middling limes 15 per cent is enough, but for limes having hydraulic properties 10 or even 6 per cent may suffice. When the proportion of clay is increased to 33 or 40 per cent, the lime obtained does not slake, but it is easily pulverized, after which when moistened, it forms a paste which sets very quickly under water. When the clay is mixed with stones or gravel, it must be washed, and the fluid mixture stirred up and made to flow over the vessel into another receptacle to subside; and when sufficiently dry, mix the liquid clay with slaked lime powder, in which state it will be found more convenient than if it were stiffer.

RESULTS AND INFERENCES OBTAINED FROM EXPERIMENTS.

From the experiments on lime and lime mortars (before described), combined with those previously tried on cement, the following inferences may be drawn :—

1st. Of the effects of sand and of Puzzolana on cement. Sand in all cases dimishes the strength of cement, whether as estimating its adhesiveness, its resistance or its water setting powers. Puzzolana is still more injurious to it than sand, as was found by a series of experiments to ascertain this point. In short every extraneous substance, excepting the carbonate of magnesia, which is far too expensive to use for building purposes in this country, (found abundantly in one part of India, and consequently, cheap) injures, and when added in a certain excess, entirely ruins cement.

2ndly. Of the effects of sand on common chalk lime, or weak hydraulic limes, such as the Halling lime. Sand appears rather to diminish the adhesiveness of chalk lime, but slightly to increase that of Halling lime, in either case the difference being insignificant. Its effect upon their resistence is more marked, especially upon that of chalk lime, which it nearly doubles, whilst it only increases that of Halling lime by one-half.

3rdly. Of the effects of sand on strongly hydraulic limes, such as the blue lias. It appears to increase both their adhesiveness and their resistance in a slight degree, and blue lias lime does not appear to be materially injured by an admixture of three parts of sand to one of lime, although two of sand to one of lime is found to make the best mortar.

ON THE CONSTRUCTION OF WATER-TIGHT ROOFS AND FIRE-PROOF FLOORS.

Water-tight roofs are constructed with two or three courses of plain tiles, which are about $10\frac{1}{2}$ inches long, $6\frac{1}{4}$ broad, and $\frac{5}{8}$ of an inch thick, and weigh about $2\frac{1}{2}$ lbs. each ; they are laid in cement

upon flat beams or rafters, placed about 4 feet apart, crossed by transverse battens, 2 inches by three inches, at intervals of 11 inches, from centre to centre; the joints of each course of tiles are broken, and the upper covering should be about an inch thick. The roof must have sufficient fall to carry off the rain, &c., and if iron bearers are substituted for timber, it would be better.

Mr. Frost contrived an ingenious method of forming fire-proof floors and roofs with square earthenware tubes measuring externally $2\frac{1}{2}$ inches square and 1 foot long. Two courses of these were laid in pure cement at right angles to each other, and formed a floor from 8 to 10 feet wide, and which was considered safe for any number of persons to walk upon. In consequence of its tubulated form it is reckoned much stronger than if made of plain tiles, or any sort of plain flat tiles of equal weight. The tubes are so arranged as to break joint with one another in both courses, and a coat of cement stucco is applied both above and below, which completes and strengthens it. They are turned in flat arches on iron beams or bearers, at 8 or 10 feet apart.

Fire-proof ceilings or roofs are constructed in like manner with arch pots, which are made square at top and round at bottom, the side of the upper square and the diameter of the lower circle being equal, $4\frac{3}{4}$ inches, and from $5\frac{3}{4}$ to 8 inches high, having the sides and bottom screwed, and a small hole in the top to receive the cement and form a key thereto: the smaller ones weigh about $2\frac{1}{2}$ lbs., and the larger about $4\frac{1}{4}$ lbs.

Ceilings of this description were formed over the basement of the Treasury buildings, Whitehall, at Buckingham Palace, the Senior United Service Club, and the National Gallery, London. Various experients, such as pieces of bricks, or half pots broken down the middle, alternating with the regular arch-pots, were used, in order to obtain proper bond at the springing of the arches, which generally abutted against stone skew-backs, on each side of the iron girders,

which were placed usually about 6 feet apart, seldom more than $7\frac{1}{2}$ feet, and never less than $4\frac{1}{2}$ feet, and their rise seldom exceeded 6 inches.

ON THE MEASUREMENT OF LIME.

Lieut.-Col. Pasley found, by experiment, that a very important difference in the apparent quantity of lime (and coals) exists under various conditions, particularly in reference to the size of the lumps or particles thereof, and it being of the utmost importance for both the interest of trade and purposes of experiment to ascertain and determine the *real* quantity contained in any *apparent* measure, he devoted much time and study to the subject which resulted in the following facts:—

1st. He found that 1 cubic foot of solid coal was broken into about 30 pieces, together with the rubbish and dust produced in the breaking, occupied $2\frac{1}{4}$ cubic feet of fair level measure, but that on further breaking the same coal into a tythe part of the size, or 300 pieces, which produced a greater quantity of rubbish, it filled $1\frac{3}{4}$ foot; but on being pounded entirely into rubbish and dust, it only filled $1\frac{1}{2}$ cubic foot. He also found that a compact 10 cubic feet measure contained a greater quantity, by about 5 per cent., than ten times the contents of a single cubic measure, in all which states the real quantity of the coal was the same, though the estimates of it by measure were so very different; and as lime is usually sold by the same measure, the difference of the *actual* quantity supplied would, in like manner as with coals, vary in proportion to the size of the component parts of a cubic foot, cubic yard, or any other measure, so that for the purposes of use in building, or for experiment, great deception and error may arise He further observes, however, that this difference in the uncertainty of measure is not so great in lime as in coals, inasmuch that the pieces of lime-stone are necessarily obliged to be broken into one uniform size for the convenience of burning, and accordingly the builder, in

purchasing his lime in lumps, by the cubic yard, may depend upon receiving nearly the same average quantity of the same sort of lime from the same kiln; the variation of different sorts of lime from different kilns seldom exceeds 10 per cent., the excess of real quantity being in favor of small pieces of kiln-burned lime, about 9 cubic yards of which will equal 10 cubic yards of the same sort of lime, when burned in a flame kiln.

DIFFERENT MODES OF MEASURING LIME.

1st. In lumps as it comes from the kiln. This is the customary mode, which, if any large compact measure, such as one containing a cubic yard, or even 10 cubic feet only, be used, will afford a tolerable fair estimate of the quantity, but not so if much smaller measures be used.

2d. In slaked lime powder. This mode was first adopted by Smeaton, at the building of the Eddystone lighthouse, and recommended by him for all hydraulic mortars; and the term applies to lime broken small and slaked by a moderate quantity of water, sprinkled over it with a watering pot, after which it should be covered up, until it falls down into a powder, for which more or less time will be required, according to the quality of the lime, but from 18 to 24 hours will be sufficient, as even the blue lias limes, which are the slowest slaking of all our English limes, from possessing the strongest hydraulic properties, do not usually require more than 18 hours.

3d. In quick-lime powder. For this purpose the lime is reduced to a fine powder, by being pounded in a mill, or by manual labor; this mode, is, however, but seldom adopted.

4th. In slaked lime putty or paste, This mode was adopted in preference by Col. Pasley in his experiments at Chatham, and applies to quick-lime fresh from the kiln, pounded in a mortar, and afterwards thoroughly slaked with a moderate quantity of water, gradually applied, until the lime, throwing out more or less heat, shall become

quite cool, and then re-mixing it with more water into a stiffish paste, in which state it is to be measured.

Lime in lumps, as in the first case, is always computed by fair level measure, rather full than otherwise. Lime in powder, as in the second and third cases, is reckoned by *strike* measure. In the fourth case, of putty or paste, it is also measured in the latter mode. A more accurate method of ascertaining the quantity of lime would be by weighing it, provided it be well burned and fresh from the kiln.

The average weight of well burned blue lias, Halling, and chalk-lime, when well burned and broken into rather small pieces, suited to the common lime-kiln, may be estimated at 49, 37 and 31½ lbs. per cubic foot, respectively.

A MODERN LIME KILN.

As an example of a modern lime-kiln of the most approved form and construction, with a full description of the structure, and of the *modus operandi* of lime-burning, a better cannot be selected than that given by Mr. Samuel Clegg, Junr. (of London), in his "Notes on Construction," published November, 1851, which is now quoted with the illustration, for the advantage and interest of all concerned in the trade.

[*Vide* plates at end of book.]

ON THE BURNING OF LIMESTONE.

In England the operation of calcination is left almost entirely to the lime-burner, and the engineer receives his material in the state of quick-lime, the virtue of which is generally so well known, that he mixes it up for extensive use without previous trial of its virtues. This, however, would not be the case in new countries, or in those districts removed from spots where lime-burning is carried on as a trade; he must then be his own lime-burner, and the knowledge of the best processes followed, both as to fuel and form of kiln, must be studied by him.

The art of lime-burning consists in calcining the greatest quantity of material with the least expenditure fuel, of time and of manual labor. To gain this end, the preparation of the lime-stone its arrangement in the kiln, the disposition of the fuel, the regulation of the heat and draught, and the proper coloring of the lime must be attended to. The general process will probably be more easily understood by first giving a description of a kiln and the manipulation necessary, and then proceeding to more minute matters.

THE KILN.

The kiln shown in the wood-cut called a "flare or dome kiln," is used by the most extensive lime-burners in Dorking, and is similar to all those used in the vicinity of London, only they are sometimes placed in pairs or three or four together; this arrangement, by exposing a less surface of wall to the cold air, slightly diminishes the expenditure of fuel; but is probably adopted more with a view of saving labor than fuel, as the fireman has all the fires under his immediate control. The interior of the kiln is of a circular bottle shape, the diameter at the bottom being 10 feet 6 inches, the wall is carried up plumb to a height of 7 feet, at which point the dome is commenced, which closes in the kiln, leaving only an opening at the top 1 foot 8 inches diameter and 2 feet high as a chimney; the total height from the hearth to the top of the chimney being 19 feet 6 inches. The thickness of the brickwork, to a height of 11 feet, is 14 inches, which is the level of the top of a surrounding wall of rubble work; from this height to the top, the thickness is nine inches, including the lining of fire-brick. The surrounding wall is of a horse-shoe form, the circular part 20 feet in diameter, and the depth from front to back 19 feet; it is about 18 inches thick, batters, about 6 inches, and the space between it and the brickwork of the kiln, is filled in with rubbish. At the back of the kiln and 3 feet 6 inches above the grate bars, a doorway is made, 6 feet 6 inches high, and 4 feet 8 inches wide, arched over with 9 inches brick-work, through which the kiln is filled. On the opposite

side to this opening are two furnace doors, the grates 18 inches wide, extending to the back of the kiln. The furnace mouths are funnel shaped, and are 3 feet 6 inches high above the grates in the inside. This construction makes it convenient for turning the rough arches of the limestone when filling the kiln. A shed is built on this side to protect the workmen and the fuel from the weather.

CHARGING THE KILN.

In charging the kiln, brushwood is laid over the grates, with a stratum of coals upon it to form the fire. Large lumps of limestone, or chalk, are then brought in at the door-way, and a rough arch, about 3 feet high and 2 feet wide, is firmly built over each grate, that the superincumbent weight of the stone may not crush them. The lumps are generally trimmed to shape that they may bed properly upon these arches. The general mass of stone to be burnt is then thrown in, care being taken to keep the largest stones at the bottom, and where the greatest heat will be, and gradually to diminish the size towards the top, where the small pieces are placed. The top of the charge is about on a level with the surrounding rubble wall. Some care is taken to have the interstices between the lumps of stone as large as possible, by placing the angles in contact; the object of this is to facilitate the calcination of the large lumps, for if the smaller pieces were mixed with larger, they would be "over-burnt" * before the latter were nearly calcined; there is a greater draught also when the spaces between the stones are greater, and this likewise assists to burn the large lumps as quickly as the small. When compact limestone is to be burnt, it should be broken into pieces not exceeding a fist in size. Chalk lumps may be much larger. If the stones are

* Pure lime is incombustible, and therefore cannot be over-burnt, but lime containing the impurities necessary to render it a weather lime, easily fuses and becomes covered with a kind of enamel; it slakes with great difficulty, sometimes it will not slake at all, but becomes reduced to a harsh powder, altogether *inert*, and is called *dead* lime.

broken into too small pieces, the spaces between them will not give free passage enough to the draught and flame. The stone thrown into the kiln should not be too dry: its state just as taken from the quarry is the best; if it has lost much of its natural moisture by lying by. Water should be sprinkled over it with a rose. The reason of moisture being useful, is, that the vapor from it facilitates the disengagement of the carbonic acid gas, by reason of its great affinity for water; the stones, however, must not be wet.

THE BURNING.

In commencing the operation of burning, the fire must be lighted, and the heat of the kiln very gradually raised; from 15 to 20 hours being suffered to elapse before the whole intensity of the fuel and draught is allowed to be felt. To keep the fire down, as little air as possible must be allowed to pass through the grate bars; and if there are not shutters or dampers to the ash-pits, lumps of stone may be built up before them, to be gradually removed as greater draught is required. The effect of raising the heat too suddenly would be to destroy the rough arches over the grates, when the mass above them would fall and smother the fire; also the lumps of stone would splinter, and the splinters filling the air spaces between them would destroy the draught. This attention to the gentle increase of the heat is more especially necessary in a new kiln, when the sudden heat would burst the green work; hooping the kiln with iron, to prevent this kind of danger, is therefore practiced. When the calcination is complete, the color of the flame from the chimney will be either of a pale, yellow or a white, with no smoke; the stone in the kiln will have settled down to an extent of a fifth or a sixth of the entire mass, and the whole will present a glowing red heat, or a whitish rosy tint. The experienced lime-burner well knows by these indications that his charge is worked out; but those who have not had much practice, should take out a piece of the stone from the kiln, remove the outer coating, and slake the inside portion in water; if no effer-

vescence ensues upon the application of an acid having a stronger affinity for the base than the carbonic acid (nitric or sulphuric acid, for instance), the calcination is complete. When this is ascertained to be the case, the fire may be raked out, and the kiln suffered to cool gradually. If the ash-pits and air-vents are closed, the effect will be favorable to the lime, which will be harder, and will keep longer exposed to the air, so that it can be conveyed to greater distance without deterioration; but for a long journey, or if the lime is not to be used for some time, it should be put into tight casks.

A flare kiln, containing 45 yards of Dorking gray chalk takes 48 hours to burn, and consumes about 7 tons of coal, the quantity depending somewhat upon the dryness of the chalk, but the variation is very inconsiderable, never exceeding five or six sacks (10 or 12 cwt.)

The cost of such a kiln of lime is about the following:—

	£ s. *d.*		American Currency.
Blasting and digging in the quarry, . .	0 12 0	or	$2 88
Carting (dependent on the distance) say . .	0 10 6		2 52
Turning rough arches, and filling, . .	0 16 0		3 84
Labor for burning, ...	0 18 0		4 32
Emptying at 3*d.* per cubic yard, . . .	0 11 3		2 70
	£3 7 9	or	$16 26

To this must be added the price of seven tons of coal used as fuel, and the value of the land from which the limestone is taken. The price in London for Dorking lime is ten shillings per cubic yard, or $2.40.

A kiln in constant use will not last more than eighteen months or two years, without it be re-lined. It is economy, therefore, to use the best Stourbridge bricks or other fire-bricks, set in fire-clay, in the original construction.

In selecting a position for the kiln, the spot should be chosen as near to the quarry as possible, for as the stone loses about 45 per cent

in burning, it is a saving in the carriage of the remaining 55 per cent. A sloping bank should also be chosen, that the natural ground may be on a level at the back of the bottom of the hatchway, and at the front with the bottom of the ash-pits.

DESCRIPTION OF THE CEMENT KILN USED AT SHEERNESS DOCKYARD.

The form differs in nothing from the inverted, conical frustum-shaped lime-kilns; and the size may be varied according to circumstances; but when not built upon the side of a cliff or hill, as is usually the case, they are sometimes built in the external form of small cylindrical brick towers, with strong iron hoops, and sometimes also with vertical bars, to prevent the fire splitting the brickwork.

The kiln designed and built by Mr. Rennie, C. E., at Sheerness dockyard (and which is considered of a very convenient construction) is a mass of brickwork, measuring 17 feet in external diameter and 21 ½ feet in extreme height. The hollow inverted conical frustum is 8 feet clear diameter at top and 5½ feet at bottom, a 9-inch ring of brickwork incloses this space, surrounded by the brickwork in mass. At the bottom of it there is a sort of small solid dome, 2 feet 3 inches high, for the purpose of throwing off the calcined cement, and to cause it to fall down through the ash-holes of four openings, or "eyes," as they are technically termed, at the bottom of the kiln, formed in recesses which are arched over, and increased to 6 feet 3 inches in width, and 7 feet 6 inches in height, at the outside. These ash-holes are 2 feet 6 inches wide, and 18 inches high to the crown of the flat arch which covers them, and over each, at the interval of 15 inches higher, there are fire-holes 12 inches square, within the same recesses, having iron bars at top, to support the brickwork above them.

Plate 2 (see end of the book), Figs. 1, 2 and 3, represents the construction of the above-described kiln, with the exception of the parapet wall or railing which is attached around the top of the kiln to prevent the workmen falling over.

There are four wrought iron hoops inclosing the brickwork, as shown in Fig. 2, each 3 inches wide, and 3-8 of an inch thick, which are formed in several pieces, connected together at the joints by strong vertical iron bolts, similar to a hinge. The plan, Fig. 3, represents a horizontal section, taken on the level of the ash-holes (or eyes), in which the voids are left blank and the solid parts shaded. This kiln will contain nearly 30 tons of broken cement-stone, averaging 26 cubic feet to the ton, exclusive of the fuel necessary to burn the cement stone.

THE OPERATION OF BURNING.

The bottom of the kiln is first filled with shavings and wood, after which the coals and cement-stone are added in alternate layers, the former being broken so small that they occupy little more space than necessary to fill the interstices between the strata of the latter, each of which is usually one foot in height or thickness.

Three days after the kiln is lighted, the calcined cement should be drawn, whilst laying on more coals and raw cement-stone at the top, so as to keep it continually burning; the kiln may be drawn every twenty-four hours. Each ton of cement-stone produces about about 21 bushels of cement-powder.

Sometimes two such kilns are built near to each other, and connected by a bridge at top, and a crane or derrick fixed there to raise the cement-stone and fuel, and to deposit it where and when required. It is not always customary to make the inclosing brickwork so thick as before described, but the width at the top is increased by a projecting balcony, the ascent to which is by an outside stairway.

Mr. Mitchell recommends the introduction of chains in addition to the external hoops, the better to resist the tendency of the fire to split

the brick-work; and Col. Pasley suggests a kiln of the form shown in Plate 3, which is a vertical section thereof. It is of rather an oval form, instead of the inverted frustum of a cone, having its greatest diameter some little distance from the top; this kiln is of the same height as the one before described, and of the same diameter at bottom, and from thence increasing to 8 feet at about two-thirds of the way up, and again diminishing to 6 feet in clear diameter at top.

The calcined cement is afterwards to be ground in a proper mill, and passed through dressing sieves similar to flour, and immediately packed in tight casks or bags for use.

RULE FOR MAKING AN ARTIFICIAL CEMENT, WHEN HARD LIME-STONE ONLY CAN BE PROCURED.

Supposing that no chalk can be procured, but only hard lime-stone, which must be burned and slaked before it is mixed with the clay, as it would be too expensive to grind, and supposing further that it is as hard as marble (or nearly a pure carbonate of lime), the same proportion of chalk to clay, by weight, which made the best cement mixture will also fix the proportion of lime-stone to the clay; but instead of weighing the former in its natural state, it will be better to weigh it as quick-lime after it comes from the kiln, in which state 40 lbs. of lime to 100 lbs. of blue clay, or 30 lbs. of lime to 1 cubic foot of clay, because the best proportion of chalk or natural lime-stone to the blue clay, by weight, is as 100 to 137 ½, and the produce of 100 lbs. of pure carbonate of lime is only about 55 ½ lbs. of quick-lime, but as 55 is to 137 ½, so is 40 to 100 nearly, which last proportion has been chosen as the more simple and easily remembered. Again, as 40 is to 100, so is 39 to 97 ½ nearly; the last number being the weight in pounds of one cubic foot of fresh blue clay; or 39 lbs. of lime to one cubic foot of this clay, will be the proper proportion. Let there-

fore, the lime, fresh from the kiln, be weighed in portions of 39 lbs., and mixed with sufficient water to form lumps of lime-paste, of a thinnish consistency, and in about twenty-four hours afterwards, mix each of these lumps with one cubic foot of the blue clay, and the whole incorporated with a pug mill; after which, the process of making the mixture into balls, and drying, burning, and grinding will be the same as in working with chalk-paste and clay.

It will require one measure of coals for burning eight measures of the raw cement balls

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RULES FOR MAKING AN ARTIFICIAL CEMENT EQUAL TO THE BEST NATURAL WATER CEMENTS OF ENGLAND.

1st. The ingredients: White or upper chalk of the geologists, which is one of the purest carbonates of lime, and which is always intermixed with a thin strata or nodules of flint. These must be separated, and the chalk either ground dry to an impalpable powder, or, by the aid of water, reduced to an impalpable paste. Marly, or impure chalk, usually found near the surface of the ground, must be rejected.

Blue alluvial clay of lakes or rivers, in a state of minute division, and free from sand, procurable from rivers of moderate rapidity; the brown surface with which alluvial clay is usually covered must be rejected; and care must be taken that the clay does not become stale by exposure to air, which gradually destroys its color and robs it of its virtue as an ingredient for a water-cement. Where alluvial clay is not to be had, fine pit clay will answer the same purpose.

The clay, if not required for immediate use, should be preserved in compact iron vessels, of a cubical form, closely pressed in, and covered with a little water, to exclude the air and keep it moist.

2d. Proportions of the ingredients: The best proportion is 100 lbs. of pure chalk, perfectly dry, mixed with 137 ½ lbs. of fresh blue alluvial clay, being equivalent to C 4, B 5.5,* which proved the strongest of all our experimental artificial cement mixtures; or if by measure, 1 cubic foot chalk paste, reduced to the consistence of stiff mortar, mixed with 1 ½ cubic foot of fresh alluvial clay; the required consistency will be obtained by mixing 1 lb. of dry chalk-powder with 7 ½ cubic inches of water, which will produce 18 cubic inches of paste, as required; so that there will be 96 lbs. of dry chalk to every cubic foot of paste. But these proportions are subject to variation according to the nature or quality of the several materials, and which can only be determined by actual experiment.

3d. Mode of grinding the chalk: It must first be broken into small pieces, and then ground with water in a wash mill (such as used by whitening-makers), or in a mortar mill (pug mill), both of which being in common use are doubtless well known to our readers.

4th. Mode of mixing the chalk and clay: The former, when ground with water in one of the mills just described, would probably be in too fluid a state for immediate use. The superfluous water must therefore be partly drained off, and partly evaporated, by allowing it to drain under cover from the weather, until the chalk-paste is brought to a proper consistency; but if too dry, water must be added as required. It must be then mixed with the blue clay, by means of a couple of small measures, the capacity of which must be as 1 to 1 ½, the former for measuring the chalk-paste and the latter, the clay; the contents of which must be alternately emptied upon each other into the pug mill, until it is quite full; then set the mill in motion, and pass the contents through, which, if not perfectly incorporated together by the first operation, must be passed through a second time. The measures used should be of a convenient size, neither too small nor too large.

* Note. C signifies best class chalk-lime, and B the blue lias clay.

5th. Mode of preparing the raw cement for the kiln: After passing through the pug mill, the raw cement mixture must be made up into balls of about 2 ½ inches diameter, by the hands, which can be performed by women or children. The balls must be allowed to dry, so as not to stick together when in contact, nor to be easily crushed by the superincumbent weight to which they will afterwards be exposed in the kiln, for which purpose 48 hours' exposure to the air under cover will probably suffice.

Balls of a smaller size would be liable to spoil by exposure, and larger ones would not be so convenient for burning.

VARIOUS RULES FOR TESTING THE QUALITIES OF CEMENTS.

1st. Rule for judging whether the cement supplied by a manufacturer is in a proper state for use:—

Mix up the cement-powder with water and make four or five experimental balls of it, not exceeding an inch in diameter. Allow them to set with warmth, and cool again, which, in good but rather slow-setting cement, will require about half an hour; after which put two or three of them into a basin of water. If they continue to set in this state, and become very hard in the course of a day or two, the cement is good; but if on the contrary they do not become very hard in this time, both inside and out, whether previously kept in air or water, the cement is not in a fit state to be used, and should be rejected.

2ndly. Rule for ascertaining whether cement of improper quality has originally been good, but injured by becoming stale, or whether it may not have been either the produce of bad cement stone, or of good cement stone adulterated after calcination, which two last cases cannot be discriminated in cement prepared for sale:—

If the experimental balls, made as last described, will not set properly either in air or water, the next point is to ascertain the cause. For this purpose, burn the same balls in a crucible for two or three hours in a common fire-place, exposing them to a full red heat, until they ceased to effervesce with acids; then pound the calcined cement in a mortar till you reduce it to an impalpable powder, and mix it up once more into experimental balls with water. If the cement, after being thus re-burned, should set well both in air and under water, it is a proof that it was originally good, but had been spoiled by exposure to air and damp.

If on the contrary the cement was in a state unfit for use, should not be improved by the above process, which completely restores the virtue not only of stale cement if originally good, but also of stale lime, it is a proof that it has either been made of inferior cement stone, or that it has been adulterated by mixing earth or sand of the same color, with the cement powder.

3dly. Rule for judging of the comparative cohesive strength of different sorts of cement:—

Having ascertained that the cements to be compared together are in a serviceable state, by the the foregoing rules, without which further trouble would be useless, two modes present themselves for judging of their comparative strength; one, the usual mode of setting out bricks from a wall or forming a suspensory arch, and the other, by what is termed the breaking-down apparatus, consisting of a scale-board, planks and weights, and a couple of pairs of nippers to be used with a gyn or triangle, the operation of which we will now describe: Provide two pieces of lay stone, or any other sound hard stone, each exactly 10 inches long, 4 inches broad, and 4 inches deep, more or less, prepared with mortices in the sides, one inch wide and one inch deep, and from ½ an inch to ¾ high, to receive the nippers, which should be so placed as to have at least 2 ½ inches of solid stone above and below them; the abutting surfaces of the stone after being properly squared to match, should be jagged or roughed to

the depth of about $\frac{1}{8}$th of an inch, or indented with a mason's pick, Eight or ten pairs of such stones should be prepared for each sort of cement for the purpose of trying several experiments at the same time; these stones must be cemented together in pairs, with the different specimens of cement laid on uniformally, and with a joint not exceeding one quarter of an inch in thickness, and then allowed to remain 10 or 12 days to properly set and indurate according to the weather or the season of the year. These are to be suspended to a beam, or shears, with a scale or plank attached below to receive the weights, with which it is to be loaded; then apply the weights equally to each specimen, aud carefully note down each transaction, and register the breaking weight of each sample, the time under trial, and circumstances and nature of the fracture. The comparisons should be made separately, with the quick or slow setting cements; otherwise it will be unfair, as some cements are as fully indurated in 10 or 12 days, as others in 3 or 4 months.

In order to ascertain more precisely the effect which sand produces on the cohesion of cement, I caused three little brick masses to be connected by pure cement, and three others to be joined by a mixture of the same cement with clear sharp sand in equal parts, by measure, and in order to compare their relative cohesiveness with that of old chalk lime mortar also, I caused some little masses to be cut out of the best brick walls, built with mortar of this description, which I could find within Chatham lines; and having prepared these small specimens with proper mortices to receive the nippers, the whole were torn asunder in the usual manner, by successive weights, as stated below.

COMPARATIVE COHESIVE STRENGTH OF PURE CEMENT, OF CEMENT MIXED WITH SAND, AND OF COMMON CHALK LIME MORTAR.

No. of Expt.	*Whether with cement or chalk lime mortar.*	*Age in days or years.*	*Weight in lbs. which broke joint*	*Av'rage breaking weight in lbs.*
1	Pure cement.	11 days.	1241	1092
2		17 days.	1003	
3			1031	
1	Cement and Sand.		205	225
2		11 days.	257	
3		17 days.	343	
1	Chalk lime mortar	30 years.	334	155
2			64	
3			75	
4			47	
5			205	
6			204	

Hence it appears that pure cement is more than four times as strong at the same age, as the customary mixture of cement and sand in equal parts, as in common use. Mr. Brunel was therefore quite right in employing only pure cement in the arches of the Thames Tunnel (England), and which method ought to be adopted in all works of risk or importance. Yet in all works of less importance, the addition of an equal volume of sand is not to be reprobated, because this proportion, whilst it renders the cement mortar cheaper, is not sufficient to take away its hydraulic properties, and even when but 17 days old, it appears from these experiments to equal, if not to exceed the strength of the best lime mortar of 30 years of age, and I conceived it probable, that if tried at a greater age, the cement mortar would exceed the strength of the chalk lime mortar, in a five-fold rate.

The author (Col. Pasley) next describes a series of experiments which he made of the comparative adhesiveness of cement to bricks and various sorts of stone, the results of which appear as follows; the

period of the trials extended from the latter end of December, 1836, to the middle of May, 1837. The age of the cement was in general 11 days, in two instances only having been extended to 12 days.

The first 12 experiments were with bricks, the average fracturing weight was 1359 lbs.

The next 5 experiments were with Bath stone, average fracturing weight 1103 lbs.

Then followed 5 experiments on Cornish granite, which separated with an average weight of 900 lbs.

The next 5 experiments were with Portland stone, which fractured with an average of 856 lbs.

Then 5 experiments on Yorkshire landing stones, the average fracturing weight of which was 823 lbs.

The next 5 experiments were with Kentish rag-stone, the average breaking weight being 1349 lbs. showing the adhesive power to be nearly equal to that of bricks.

Then followed 5 experiments with Craigleith stone (Scotch) the average breaking weight being 855 lbs.

The last 2 experiments were with Cornish granite polished on the cementing surfaces, the fracturing weight of which averaged 928 lbs., which, therefore, nearly equalled in strength to experiments Nos. 4 and 5 with Cornish granite (rough) which averaged, 1213 lbs.

The discrepancies which were apparent in the results of some of the foregoing experiments, were considered to be owing to the condition of the cement, some of which were, at the time of using, more fluid than others. Upon the whole, these experiments are not fully conclusive, but we safely infer from them that the adhesiveness of cement to the least congenial sort of stone is more than one half, and nearly two-thirds of its adhesiveness to bricks, and that it appears to adhere to hard stones with a greater tenacity than to soft ones, and also that the state of the surfaces operated upon, whether more or less smooth is of very little importance, but these experiments fully

prove that pure cement attaches itself to the most refractory sort of stone with five times as much adhesive force in 11 days, as the best chalk lime used in brickwork is capable of attaining in 30 years.

ADDENDA.

AMERICAN RESOURCES.

The United States furnish excellent limestone, principally of primary formation. One range which passes unbroken through several of the States is perhaps one of the most extensive and valuable primary limestones in the world.

(Extract from Mahan's Engineering.) Limestone is so extensively diffused throughout the United States, and is quarried, either for building stone or to furnish lime, in so many localities, that it would be impracticable to enumerate all within any moderate compass. One of the most remarkable formations of this stone extends, in an uninterrupted bed, from Canada, through the States of Vermont, Massachussets, Connecticut, New York, New Jersey and Virginia, and in all probability, much further south.

Limestone is burned in almost every locality where deposits of the stone occur. Thomaston, in Maine, has supplied, for some years, most of the markets on the seaboard with a material which is considered as a superior article for ordinary building purposes. One of the greatest additions to the building resources of our country was made in the discovery of the hydraulic or water limestone of New York. The preparation of this material, so indispensable for all hydraulic works and heavy structures of stone, is carried on extensively at Rondout, on the Delaware and Hudson canal in Madison county, and is sent to every part of the United States, being in great demand for all the public works carried on under the superintendence of our civil and military engineers.

A not less valuable addition to our building materials has been

made by Prof. W. B. Rogers, who, a few years since directed the attention of engineers to the dolomites, for their good hydraulic properties. From experiments made by Vicat, in France, who first there observed the same properties in the dolomite, and from those in our own country, it appears highly probable that the magnesian limestones, containing a certain proportion of magnesia, will be found fully equal to the argillaceous, from which hydraulic lime has hitherto been solely obtained.

(Extract from Prof. Daniel's Lecture, before the Chicago Academy of Natural Science.) A magnesian limestone which forms the heights of the Upper Mississippi, extends south-west across the Wisconsin River, and westward into Minnesota. At Lasalle, Illinois, it furnishes an excellent hydraulic cement.

The Trenton limestone, 70 feet thick, is a hard, thin-bedded blue limestone, often wholly made up of shells and corals, above this is the Galena limestone, 250 feet thick. Then comes the Hudson River rocks, in whose lower portion are found shell beds as rich as those of the Trenton limestone, bnt of different species. They form the base of the mounds around Galena and through the lead region.

Joliet, the city of stone quarries, lies in the old river bed of the once mighty Des Plaines, now reduced to a small stream. East and west are rocky bluffs. The valuable and inexhaustable quarries extend more than 20 miles north and south, and near the upper end is the little town of Athens, which gives its name to the celebrated stone used in Chicago. Five miles from Joliet is Lockport, underlaid by quarries, for who has not heard of the Lockport stone? Athens comes next, and here Joliet has a competitor. The stone is of better quality, and more easily obtained. Athens is simply a vast stone quarry, and will never be anything else.

(Extract from Mahan's Engineering.) Lime considered as a building material, is now usually divided into three principal classes, common or air lime, hydraulic lime, and hydraulic or water cement.

The limestones which yield hydraulic limes and cements are either argillaceous, or magnesian, or argilo-magnesian. The products of their calcination vary considerably in their hydraulic properties. Some of the hydraulic limes harden, or set very slowly under water, while others set rapidly. The hydraulic cements set in a very short time. This diversity in the hydraulic energy of the argillaceous limestones arises from the variable proportions in which the lime and clay enter into their composition.

M. Petot, in an able work entitled, "Recherches sur la Chauffournerie," gives the following table, exhibiting those combinations, and the results obtained from their calcination:—

Lime	*Clay.*	*Resulting products.*	*Distinctive characters of the products.*
100	0	Very fat lime.	Incapable of hardening in water.
90	10	Lime, a little hydraulic.	Slakes like pure lime, when properly calcined, and hardens under water.
80	20	Do. quite hydraulic.	
70	30	Do. do.	
60	40	Plastic or hydraulic cement.	Does not slake under any circumstances, and hardens under water with rapidity.
50	50	Do. do.	
40	60	Do. do.	
30	70	Calcareous puzzolana, (brick).	Does not slake nor harden under water, unless mixed with a fat or a hydraulic lime.
20	80	Do. do. do.	
10	90	Do. do. do.	
0	100	Puzzolana of pure clay do.	Same as the preceding.

The most celebrated European hydraulic cements are obtained from argillaceous limestones, which vary but slightly in their constituent elements and properties. The following table gives the results of analysis to determine the relative proportions of lime and clay in these cements:—

LOCALITY.	LIME.	CLAY.
English (commonly known as Parker's, or Roman cement),	55·40	44·60
French (made from Bologne pebbles),	54·00	46·00
Do. (Pouilly),	42·86	57·14
Do. do.	36·37	63·63

LOCALITY.	LIME.	CLAY.
French (Baye),	21·62	78·38
Russian,	62·00	38·00

The best known hydraulic cements of the United States are manufactured in the State of New York; the following analyses of some of the hydraulic limestones, from the most noted localities, published in the Geological Report of the State of New York, 1839, are given by Dr. Beck.

ANALYSIS OF THE MANLIUS HYDRAULIC LIMESTONE

Carbonic acid,	39·80
Lime,	26·24
Magnesia,	18·80
Silica and alumina,	13·50
Oxide of iron,	1·25
Moisture and loss,	1·41
	100·00

This stone belongs to the same bed which yields the hydraulic cement obtained near Kingston, in Upper Canada.

ANALYSIS OF THE CHITTENANGO HYDRAULIC LIMESTONE BEFORE AND AFTER CALCINATION.

	UNBURNT.		BURNT.
Carbonic acid,	39·33	Carbonic acid and moisture	10·90
Lime,	25·00	Lime,	39·50
Magnesia,	17·83	Magnesia,	22·27
Silica,	11·76	Silica,	16.56
Alumina,	2·73	Alumina and oxide of iron,	10·77
Peroxide of iron,	1·50		
Moisture,	1·85		
	100·00		100·00

ANALYSIS OF THE HYDRAULIC LIMESTONE FROM ULSTER COUNTY, ALONG THE LINE OF THE DELAWARE AND HUDSON CANAL, BEFORE AND AFTER BURNING.

	UNBURNT.	BURNT.
Carbonic acid,	34·20	5·00
Lime,	25·50	37·60
Magnesia,	12·35	16·65
Silica,	15·37	22·75
Alumina,	9·13	13·40
Oxide of iron,	2·25	3·30
Bituminous matter, moisture and loss,	1·20	1·30
	100·00	100·00

The hydraulic properties of the magnesian limestones of the United States were noticed by Prof. W. B. Rogers, who, in his Report of the Geological Survey of Virginia, 1838, has given the following analysis of some of the stones from different localities :—

	No. 1.	No. 2.	No. 3.	No. 4.
Carbonate of lime,	55·80	53·23	48·20	55·03
Carbonate of magnesia,	39·20	41·00	35·76	24·16
Alumina and oxide of iron,	1·50	0·80	1·30	2·60
Silica and insoluble matter,	2·50	2·80	12·10	15·30
Water,	0·40	0·40	2·73	1·20
Loss,	0·60	1·77	0·01	1·71
	100·00	100·00	100·00	100·00

The limestone No. 1 of the above table is from Sheppardstown on the Potomac, in Virginia, it is extensively manufactured for hydraulic cement. No. 2 is from the Natural Bridge, and banks of Cedar Creek, Virginia; it makes a good hydraulic cement. No. 3 is from New York, and is extensively burned for cement. No. 4 is from Louisville, Kentucky, said to make a good cement.

M. Vicat states that a magnesian limestone of France containing the following constituents, lime 40 parts, magnesia 21, and silica 21,

yields a good hydraulic cement, and he gives the following analysis of a stone which gives a good hydraulic lime :—

Carbonate of lime,	50·60
Carbonate of magnesia,	42·00
Silica,	5·00
Alumina,	2·00
Oxide of iron,	0·40
	100·00

Experiments by several eminent chemists have extended the list of natural substances which, when properly burnt and reduced to powder, have the same properties as Puzzolana. They mostly belong to the feldspathic and schistoze rocks, and are either fine sand or clays more or less indurated.

The following table gives the results of analyses of Puzzolana, trass, a basalt, and a schistus, which, when burnt and powdered, were found to possess the properties of Puzzolana :—

	PUZZOLANA.	TRASS.	BASALT.	SCHISTUS.
Silica,	0·445	0·570	44·50	46·00
Alumina,	0·150	0·120	16·75	26·00
Lime,	0·088	0·026	9·50	4·00
Magnesia,	0·047	0·010		
Oxide of iron,	0·120	0·050	20·00	14·00
Oxide of manganese,			2 37	8·00
Potassa,	0·014	0·070		
Soda,	0·030	0·010	2·60	
Water and loss,	0·106	0·144	4·28	2·00
	1·000	1·000	100·00	100·00

All of these substances, when prepared artificially, are now generally known by the name of artificial Puzzolanas, in contradistinction to those which occur naturally.

(Extracts from Mr. Kirwan.) Puzzolana, reddish or reddish-brown, gray, or grayish-black :—That of Naples is generally gray, that of Civita Vecchia more generally reddish, or reddish-brown.

Its surface, rough, uneven, and of a baked appearance. It comes to us in pieces of from the size of a nut to that of an egg.

Its internal lustre, 0. Its transparency, 0.

Its fracture uneven, or earthy, and porous, commonly filled with particles of pumice, quartz, scoriæ, &c.

Hardness, 3; very brittle; specific gravity, from 2.570, which is that of the black, to 2.785, rarely 2.8; has an earthy smell.

It is not diffusible in cold water, but in boiling water it gradually deposits a fine earth. It does not effervesce with acids.

Heated, it assumes a darker color, and easily melts into a black slag, or with borax into a yellowish green glass.

It is magnetic before it is heated, but not after; this is the most remarkable of its properties.

By Mr. Bergman's analysis, it contains from 55 to 60 per cent. of silex, 19 to 20 of argill, and from 15 to 20 of iron.

When mixed with a small proportion of lime it quickly hardens, and this induration takes place even under water. This singular property appears to me to proceed from the magnetic state of the iron it contains, for this iron being unoxygenated, subtilely divided, and dispersed through the whole mass, and thus offering a large surface, quickly decomposes the water with which it is mixed, when made into mortar, and forms a hard substance analogous to the specular iron ore as it does in the iron tubes in which water is decomposed in Mr. Lavoiser's and Dr. Priestley's experiments; for in these the iron swells and increases in bulk, and so does Puzzolana when formed into mortar. One principal use of lime seems to be to heat the water, as while cold it cannot readily pervade the caked argill that invests the ferruginous particles, yet in time even cold water may pervade it, and produce hardness, and hence lavas become harder when moistened, as Mr. Dolomieu has observed. If the mortar be long exposed to the atmosphere, fixed air, as well as pure air, will unite to the iron, rust will be produced, and the mortar will not then harden, as Dr. Higgins has also noticed. Clay over which lava has flowed is frequently

converted into Puzzolana. But volcanic scoriæ never afford it, either because they are much calcined, or retain sulphur, or its acid.

Trass or terras. I couple this with Puzzolana on account of their similarity to each other, and not because I look upon it as constantly and necessarily, a volcanic production. On the contrary, I believe it to be generally the product of pseudo-volcanoes or external fires. It is found in many places, but principally near Andernach, in the vicinity of the Rhine, also near Frankfort, Cologne, Pleith, &c., and there called *tuffstein.* It is found in valleys some feet under the surface, to which no stream of water has had access; sometimes in columnar masses of a gray or Isabella yellow color, some round and some quadrangular, standing close to each other, and forming internally one common mass. According to Mr. Bergman, it consists of nearly the same principles as Puzzolana, only the calcareous seems more plentiful in this. Artificial terras or Puzzolana is made by burning clays or slates that abound in iron, and then grinding them to a fine powder.

Tufas. These seem to be a Puzzolana formed by nature into a mortar.

Piperino. This also seems a concretion of volcanic ashes, and is said to be the substance that covers Pompeia. It seems to differ from tufas, in containing more heterogenities, being in fact a kind of porphyry, or breccia, and being more easily decomposed by exposure to moisture and the open air, but if preserved from moisture, it hardens when exposed to the air.

Cement. In 1770 M. Loriet pretended to have discovered the secret of the cement of the ancient Romans, which, according to him, was only a mixture of powdered quick-lime with lime which had been long slaked and kept under water. The slaked lime was first to be made up with sand, earth, brick-dust &c., into mortar, and then about one-third of quick-lime in powder added to the mixture. This produced an almost instantaneous petrifaction, something like what is called the setting of alabaster. But the invention of this cement has

not succeeded to the degree the inventor expected, owing to the precision necessary in its preparation. Dr. Black informs us that a cement of this kind is certainly practicable. It is done, he says, by powdering the lime while hot from the kiln, and throwing it into a thin paste of sand and water, which, not slaking immediately, absorbs the water from the mortar by degrees, and forms a very hard mass. It is plain, he adds, that the strength of this mortar depends on using the lime hot or fresh from the kiln.

STRENGTH OF MORTARS.

A very wide range of experiments has been made, by engineers both at home and abroad, upon the resistance offered by mortars to a transversal strain, with a view to compare their qualities. As might naturally have been anticipated, these experiments have presented very diversified, and, in many instances, contradictory results.

M. Vicat gives the following as the average resistance on the square inch offered by mortars to a force of traction, the deductions being drawn from experiments on the resistance to a transversal strain:—

Mortars of very strong hydraulic lime,	170	pounds.
" ordinary "	140	"
" medium "	100	"
" common lime,	40	"
" " (bad quality)	10	"

These experiments were made upon prisms a year old, which had been exposed to the ordinary changes of weather.

General Treussart, in his work on hydraulic and common mortars, has given in detail, a large number of experiments on the transversal strength of artificial hydraulic mortars, made by submitting rectangular parallelopipeds of mortar, 6 inches in length and 2 inches square, to a transversal strain applied at the centre point between bearings 4 inches apart. From these he deduces the following practical conclusions:—

That when the parallelopipeds sustain a transversal strain varying between 220 and 330 lbs. the corresponding mortar will be suitable for common gross masonry, but that for important hydraulic works the parallelopipeds should sustain before yielding, from 330 to 440 lbs.

The only published experiments on this subject made in this country are those of Colonel Totter, appended to his translation of General Treussart's work.

From experiments, Colonel Totten deduces the following general results:—

1st. That mortar of hydraulic cement and sand is the stronger and harder as the quantity of sand is less.

2d. That common mortar is the stronger and harder as the quantity of sand is less.

3d. That any addition of common lime to a mortar of hydraulic cement and sand weakens the mortar, but that a little lime may be added without any considerable diminution of the strength of the mortar, and with a saving of expense.

4th. The strength of common mortars is considerably improved by the addition of an artificial Puzzolana, but more so by the addition of an hydraulic cement.

5th. Fine sand generally gives a stronger mortar than coarse sand.

6th. Lime slaked by sprinkling gave better results than lime slaked by drowning. A few experiments made on air-slaked lime were unfavorable to that mode of slaking.

7th. Both hydraulic and common mortar yielded better results when made with a small quantity of water than when made thin.

8th. Mortar made in the mortar-mill was found to be superior to that mixed in the usual way with a hoe.

9th. Fresh water gave better results than salt water.

STRENGTH OF CONCRETE AND BETON.

From experiments made on concrete, prepared according to the most approved process in England, by Colonel Pasley, it appears that

that this material is very inferior in strength to good brick and the weaker kinds of natural stones.

Concrete.—This term is applied by English architects and engineers, to a mortar of finely pulverized quick-lime, sand and gravel.

Beton.—The term beton is applied by French engineers to any mixture of hydraulic mortar with fragments of brick, stone, or gravel, and it is now also used by English engineers in the same sense.

From experiments made by Colonel Totten on beton, the following conclusions are drawn :—

That beton made of a mortar composed of hydraulic cement, common lime, and sand, or of a mortar of hydraulic cement and sand, without lime, was the stronger as the quantity of sand was the smaller, But there may be 0·50 of sand, 0·25 of common lime, without sensible deterioration, and as much as 1·00 of sand, and 0·25 of lime. without great loss of strength.

Beton made with just sufficient mortar to fill the void spaces between the fragments of stone was found to be less strong than that made with double this bulk of mortar. But Colonel Totten remarks, that this result is perhaps attributable to the difficulty of causing so small a quantity of mortar to penetrate the voids, and unite all the fragments perfectly, in experiments made on a small scale.

The strongest beton was obtained by using quite small fragments of brick, and the weakest from small, rounded, stone gravel.

A beton formed by pouring grout among fragments of stone or brick, was inferior in strength to that made in the usual way with mortar.

Comparing the strength of the betons on which the experiments were made, which were eight months old when tried, with that of a sample of sound red sandstone of good quality, it appears that the strongest prisms of beton were only half as strong as the sandstone.

Previous to giving my experiments and by way of conclusion I will just remark that, in making computations it will be quite safe to estimate a cubic foot of mortar at 108 to 110 lbs. Tenacity 50 lbs. to

the square inch, and specific gravity 1·75; sand at 90 to 120 lbs.; unslaked lime 53 to 90 lbs.; brick-dust and brick-work at 112 lbs., and limestone at 171 to 197 lbs. Mr. Kirwan gives the weight of a cubic foot of Puzzolana at 169·37 lbs. and specific gravity 2·67.

THE FOLLOWING ARE THE RESULTS OF VARIOUS EXPERIMENTS.

No. 1. A. Stearns & Co., Bridgeport Kiln, Prairie Stone.

Thirty-three cubic inches of unslaked lime weighed 23 ounces, gave, as a result after being slaked by sprinkling, a volume of 82.5 cubic inches and weighed 28.5 ounces, equal to 2.5 of slaked lime to 1 of unslaked.

No. 1.

33.0	cubic in.	fine sand	27 ozs.	Mixed as mortar, and when perfectly dried measured 48 cubic ins. and weigh'd 45 oz.
16.5	"	Utica hydraulic cement	8 "	
16.5	"	slaked lime	5.7 "	
66.0			40.7	

No. 2.

33.00	cubic in.	sand	27.00 ozs.	Mixed as mortar, and when perfectly dried measured 34 cubic ins. and weigh'd 38 oz.
8.25	"	Utica cement	4.00 "	
8.25	"	slaked lime	2.85 "	
49.50			33.85	

No. 3.

16.50	cubic in.	slaked lime	5.70 ozs.	Mixed as mortar, and when perfectly dried meas-ur'd 23.20 cub'c in. and weigh'd 20 oz.
5.50	"	brick-dust	5.59 "	
11.00	"	sand	9.00 "	
33.00			20.29	

No. 4.

16.50 cubic in. Utica cement,	8.00 ozs.	Mixed as above, and when perfectly dried measured 16 cubic ins. and weighed 11.50 oz.

No. 5.

16.50 cubic in. sand	13.50 ozs.	Mixed as above, and when perfectly dried measured 45 cubic ins. and weighed 39 ozs.
16.50 " pounded brick	16.77 "	
16.50 " Utica cement	8.00 "	
8.25 " slaked lime	2.85 "	
57.75	41.12	

No. 6.

16.50 cubic in. slaked lime	5.7 ozs.	Mixed as lime putty, when perfectly dried, measur'd 12·75 cub'c in. and weigh'd 7 oz.

No. 7.

8.25 cubic in. slaked lime	2.85 ozs.	Mixed as above, and when perfectly dried measured 13.57 cubics ins. and weighed 10 oz.
8.25 " Utica cement	4.00 "	
16.50	6.85	

No. 2. B. STEARNS & CO., BRIDGEPORT KILN, PRAIRIE STONE.

58 cubic inches of unslaked lime weighed 48·50 ozs., gave, as a result after being slaked by sprinkling, a volume of 206·25 cubic inches of slaked lime and weighed 57 ounces, equal to 3·55 of slaked lime to 1 of unslaked.

No. 8.

203·00 cubic inches of sand,	166·70 ozs.	Mixed as mortar as 7 of sand to 1 o unslaked lime, and when thoroughly dried measured 201·13 cubic ins, and weighed 209 ounces.
103·12 " slaked lime,	28·50 "	
306·12	195·20	

No. 9.

103·12 cubic ins. slaked lime,	28·50 ozs.	Mixed as lim putty and pressed into a mould and when thoroughly dried measured 54·60 cubic inches and weighed 30 ounces. This contracted in dry'g 4·65 cubic ins.

No. 3. C. SHERMAN & CO., LYONS KILN, PRAIRIE STONE.

8·90 cubic inches of unslaked lime weighed 7·5 ounces, gave, as a result after being slaked by sprinkling, a volume of 23·29 cubic inches of slaked lime, and weighed 9 ounces, equal to 2·62 of slaked lime to 1 of unslaked.

No. 10.

23·29 cubic inches slaked lime,	9 ozs.	Mixed as lime putty and pressed into a mould and when thoroughly dried measured 15.85 cubic inches and weighed 9·5 ozs. This contracted in dry'g 1·67 cubic in.

No. 4. D. STURTEVANT & CO., KILN NEAR LYONS, PRAIRIE STONE.

16·80 cubic inches of unslaked lime weighed 14 ounces, gave as a result after being slaked by drowning, a volume of 55 cubic inches of slaked lime, and weighed 17 ounces, equal to 3·33 of slaked lime to 1 of unslaked.

No. 11.

82·5 cubic inches of fine and coarse sand,	67·50 ozs.	Mixed as mortar as 1 1-2 of sand to 1 of slaked lime or as 5 of sand to 1 of unslaked lime, nearly, and when perfectly dried measured 97 cubic ins. weighed 100 ozs.
55·0 " " slaked lime,	17·00 "	
137.5	$4·50	

COMPARATIVE RESULTS.

No.	Names of Materials.	Weight of 1 cubic ft. in lbs.
1	2 measures of sand, 1 Utica hydraulic cement, 1 slaked lime (mortar)..	101.25
2	2 " sand, ½ Utica hydraulic cement, ½ slaked lime (mortar)..	120.70
3	⅔ " sand, ⅓ brick-dust, 1 slaked lime (mortar)......	93.10
4	1 " Utica cement (without sand)......................	75.27
5	1 " sand, 1 brick-dust, 1 cement, ½ slaked lime (mortar)..	93.60
6	1 " slaked lime as putty (1st experiment)..........	63.57
7	½ " slaked lime, ½ Utica cement......................	79.58
8	7 " sand to 1 of unslaked lime (mortar)............	112.22
9	1 " slaked lime as putty (2d experiment)...-......	65.59
10	1 " " " " (3d ")..........	64.08
11	1½ " sand, 1 of slaked lime (mortar)..................	111.33
12	1 " Utica cement exposed to the air 5 months before being mixed, and then dried for 3 months..	96.77
13	1 " Sandusky cement, fresh from cask (without sand)..	85.71
14	1 measure Utica cement 1 1-2 of sand, under water for 12 months, and then dried for 3 months	117·02
15	1 " Utica cement, 2 of sand,...........................	121·93
16	1 " Utica cement, 1 of sand,...........................	114·54
17	1 " sand, 1 slaked lime (mortar).....................	102·12
18	Utica hydraulic cement, in a dry state (in cask)...........	52·36
19	Unslaked lime, in a dry state (1st experiment,)............	75·27
20	" " " (2d ")...........	90·31
21	" " " (3d ")...........	91·01
22	" " " (4th ")...........	90.00
23	Slaked lime, " (1st ")...........	37·30
24	" " " (2d ")...........	29·88
25	" " " (3d ")...........	41·72
26	" " " (4th ")...........	33·38
27	Brick dust, "	110·00

COMPARATIVE RESULTS—Continued.

No.	Names of Materials.	Weight of 1 cubic ft. in lbs.
28	Fine sand, in a dry state, (Lake Michigan)................	88·36
29	" " larger grains, in a dry state, (Lake Michigan)	94·90
30	Coarse sand, large grain, in a dry state (pit sand)........	124·36

NOTE.—M. Berthier says that a late analysis of Parker's Roman cement shows that its constituents are of chalk and common clay and he proposes the manufacture of a similar cement by the mere mixture of them in certain proportions. Thus one part of the clay and two and a half parts of the chalk set almost instantly, and may, therefore, be regarded as Roman cement.

FINIS.

PLATE I.

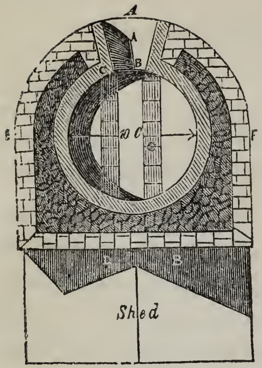


FIG. 1.

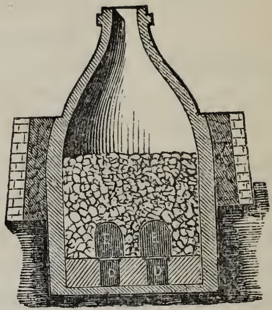


FIG. 2.

FIG. 3.

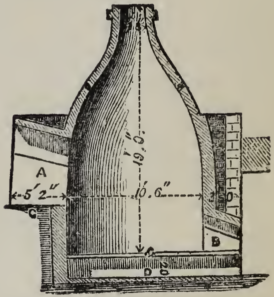


FIG. 4.

Fig. 1, plan (or horizontal section). Fig. 2, section on line E—F. Fig. 3, section on shed, and part of exterior. Fig. 4, section from A towards the shed.

A Hatchway. B Furnace. C Grate-bars. D Ash-pit. E Rough chalk-ashes. F Level of ground beneath shed. G Level of ground at hatchway.

PLATE II.

Fig. 1 *a*.

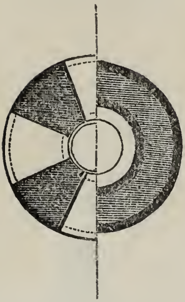


Fig. 1 *b*.

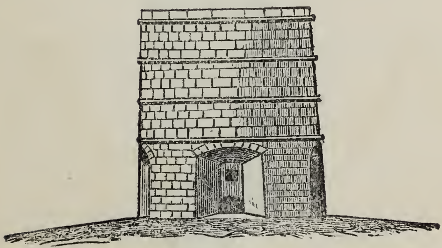


Fig. 2.

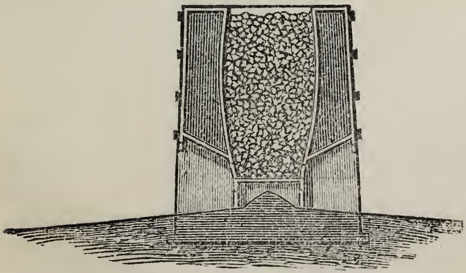
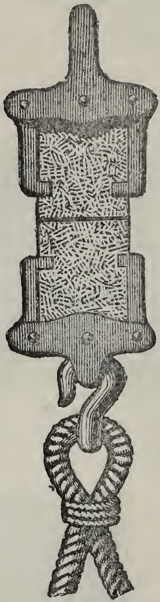


Fig. 3.

CEMENT KILN.

PLATE III.



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